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Geophysical and Petro-Structural Characteristics of the Tarkwaïan and Associated Formations of the Gontougo Region (Northeastern Côte d'Ivoire)

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Abstract

Studies carried out in the Gontougo region aimed to describe the physical and petro-structural properties of the Tarkwaian formations of northeastern Côte d'Ivoire. The methodology developed is focused on the one hand on the gravimetric geophysical method and on the other hand, on petro-structural studies. The geophysical results highlighted two gravimetric facies characterized respectively by high density ($\Delta Bg > 121$ mGal) and low density ($\Delta Bg < 114$ mGal) anomalies. From a lithological point of view, the denser domains are made up of intrusive rocks dominated by granodiorites and tonalites cutting low density facies composed of Tarkwaian formations (polygenic conglomerates and arkosic sandstones) and volcanics (tuffs and cinerites). Structurally, these different lithological groups are affected by brittle (fractures, faults, strike-slip) and ductile (folds, schistosities and mineral lineations) deformations. These structures are mainly oriented NNW-SSW, WNW-ESE and NE-SW. The description of the sulphide minerals reveals a style of gold mineralization of the Tarkwaian formations.

Keywords

Gravimetric Method, Petro-Structural Study, Tarkwaïen, Gontougo Region, Côte d'Ivoire

1. Introduction

The Tarkwa or Tarkwaian Group is defined in the West African Craton [1] [2] [3]. It is particularly well known and studied in Ghana, where it hosts significant gold mineralization (Tarkwa, Ntronang, Bippo Bin, Damang). The Tarkwaian is usually considered to be the detritus of Birimian rocks that were exhumed and eroded during the Eburnian tectonothermal event [4] [5].

In the Gontougo region of northeastern Côte d'Ivoire, the characterization of the less-studied Tarkwaïan sedimentary formations has raised much speculation to date. These are trapped in the Bui belt, dominated by green rocks of Paleoproterozoic age that extend as far as northwestern neighboring Ghana [6] [7]. From a genetic point of view, the tectonic origin of the basins remains debatable. According to [8], the Tarkwaian rocks were deposited in elongated rift basins, while a foreland basin origin has been proposed by other authors [9]. In Ghana, the greatest concentrations of paleoplacer gold in the Tarkwa-Damang district are found in the Tarkwa deposit, comprising a succession of stacked, tabular paleoplacer units (40 to 110 m thick) [3]. Given the complexity and importance of the Tarkwaian formations in Ghana, both scientifically and economically, there is a need to study them in detail in Côte d'Ivoire. The aim of this study is to describe the physical and petro-structural properties of the Tarkwaïan formations of northeastern Côte d'Ivoire.

2. Geographical and Geological Context

2.1. Geographical Context

Located in the northeast of Côte d'Ivoire, the Gontougo region covers an area of 16,770 km^2. It is bordered to the north by the Bounkani region, to the south by the Indénié-Djuablin region, to the east by the Republic of Ghana, to the northwest by the Hambol region and to the southwest by the Iffou region (**Figure 1**).

The relief is generally flat, but there is a mountain range known as Mount Zanzan, which circles the department and is very visible in the Kouassi-N'dawa area and in the sub-prefectures of Appimandoum and Pinda-Boroko [10].

The region is located in a so-called Sahelian climate zone, characterized by a long rainy season (May-July) and a long dry season (November-April). The harmattan is very harsh in December and January. The hydrographic network consists of a few streams that dry up throughout the dry season.

The vegetation is essentially tree and shrub savannah with gallery forests. There are forest islands on the plateaus and gallery forests linked to the hydrographic network in the western part of the study area. Timber harvesting is a major activity here. In the east, we also find gallery forests that follow watercourses, but above all vast stretches of wooded savannah [11].

2.2. Local Geological Context

Situated in the Paleoproterozoic domain, the geological formations of the Bondoukou region were structured during the Eburnian orogeny. The very open petrographic range of geological formations in the Bondoukou region and the complexity of structural phenomena make them difficult to study. From a lithological point of view, the study area is covered by a complex set of geological formations. Two distinct domains can be distinguished: the Quaternary (Holocene) and the Paleoproterozoic (**Figure 2**). The Quaternary formations are the most recent in the Bondoukou region and consist of leached sands and mud, as well as lateritic armour [12]. Paleoproterozoic formations occupy virtually the entire surface of the study area, and include Tarkwaian, intrusive, volcanic and sedimentary assemblages. According to [10], the Tarkwaian formations rest in unconformity on other Paleoproterozoic formations, notably metavolcanites to the north, metasediments to the south and intrusive rocks (granodiorites, tonalites) and are interpreted as representing syn-orogenic to late basins [13]. Structural data would indicate that the Birimian and Tarkwaian rocks were jointly deformed during a single progressive deformation event [5].

3. Materials and Methods

3.1. Working Materials

3.1.1. Gravimetric Data

The geophysical data used in this work come from gravimetric data downloaded from the Bureau Gravimétrique International (BGI; http://bgi.omp.obs-mip.fr/) in dat file format.

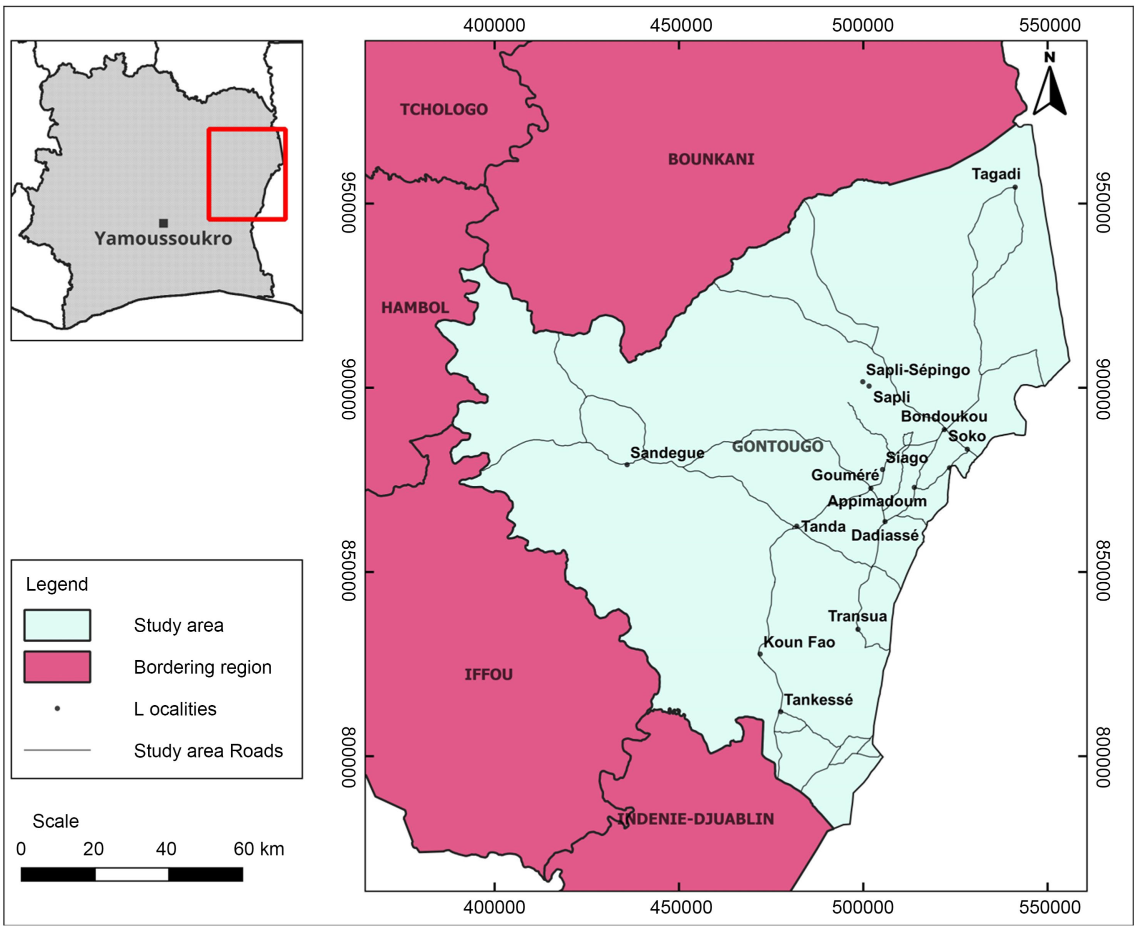


Figure 1. Location of study area.

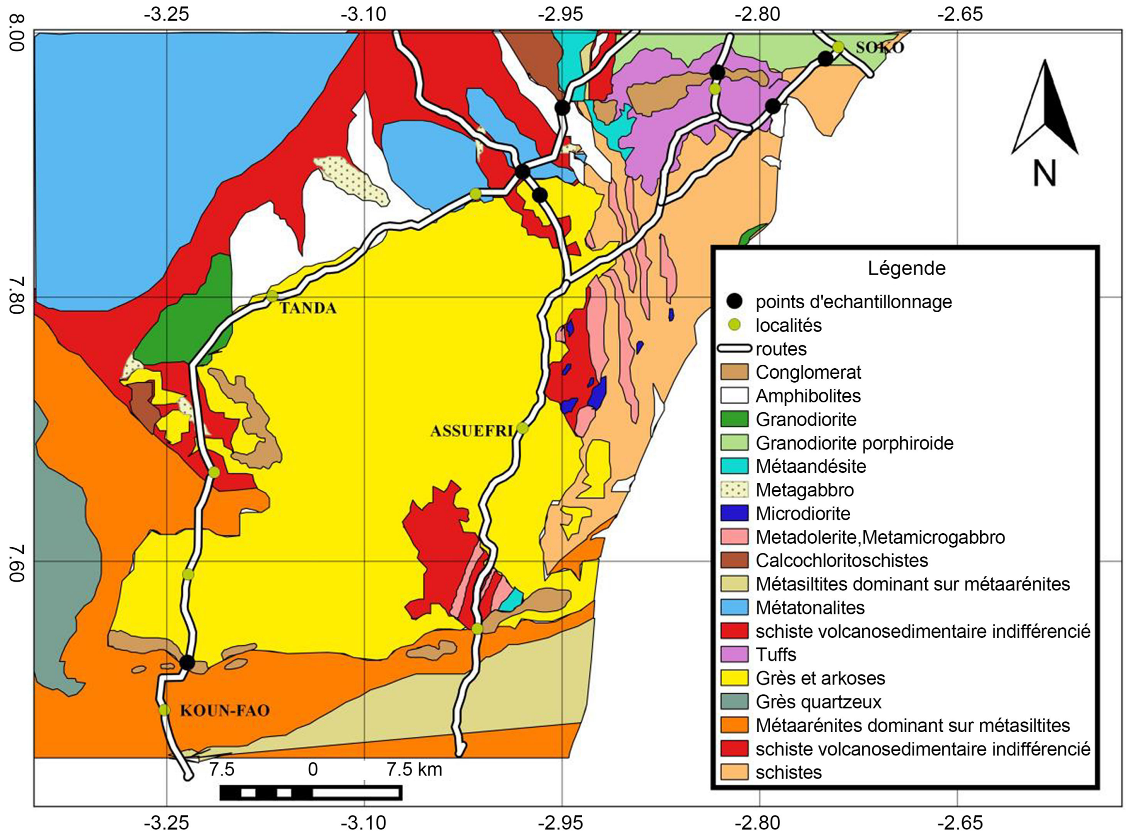


Figure 2. Geological map of the study area [10].

3.1.2. Field Equipment

As part of this project, rock samples were taken in the field to validate gravity anomalies. The equipment used consisted of: a GPS (global positioning system), a geologist's hammer, a clinometer compass, a sledgehammer, a chisel, a digital camera, a road map of the region, and the geological map of the area.

3.1.3. Laboratory Equipment

Laboratory work was carried out at the Laboratoire de Géologie, Ressources Minérales and Energétiques of the Université Félix Houphouët Boigny. Thin sections were made to describe the mineralogical composition of the formations in each zone. A polarizing microscope and camera were used to study and photograph the various thin sections.

3.1.4. Computer Hardware

Data processing was made possible using the following software:

- QGIS 3.18 is used for digitizing and producing location and geological maps;
- Geosoft 8.1. This enabled us to combine road and geological maps, to facilitate fieldwork.

3.2. Methods Used

3.2.1. Gravimetric Method

The gravimetric prospecting geophysics method applied to sub-surface studies aims to detect variations in terrain density. The physical quantity involved is gravity ($\vec{g}$). The data used in this approach are those of the Bouguer anomaly. The value of the Bouguer anomaly measured at a given point on the earth's surface reflects the density of the underlying rock [14]. There is therefore a correlation between spatial variations in Bouguer anomaly and lithologies through their density.

Data processing led to the production of the Bouguer anomaly map using Geosoft software by the spatial kriging interpolation method of Matheron (1962, 1963a, b) in [15]. A vertical derivative (dz) was applied to the Bouguer anomaly to highlight lithological contacts. Anomaly interpretation is based on the local geological map and geological field observations.

3.2.2. Macroscopic Petrography

Macroscopic petrography consists in describing the lithological units of the samples taken from the outcrops encountered. The aim is to find or propose a name for the rock, based on the various classification criteria of texture, structure, mineralogical composition and color.

3.2.3. Structural Analysis

This involved making observations on the rocks and their deformation, identifying structural elements (stratification, schistosity, foliation, lineation, fracture, fold, etc.) and taking measurements to study deformation.

3.2.4. Microscopic Petrography

Rock samples were taken to make thin sections for microscopic study. The mineralogical assemblages observed were used to refine the petrographic and structural studies carried out in the field. They also enable us to characterize the different metamorphic facies.

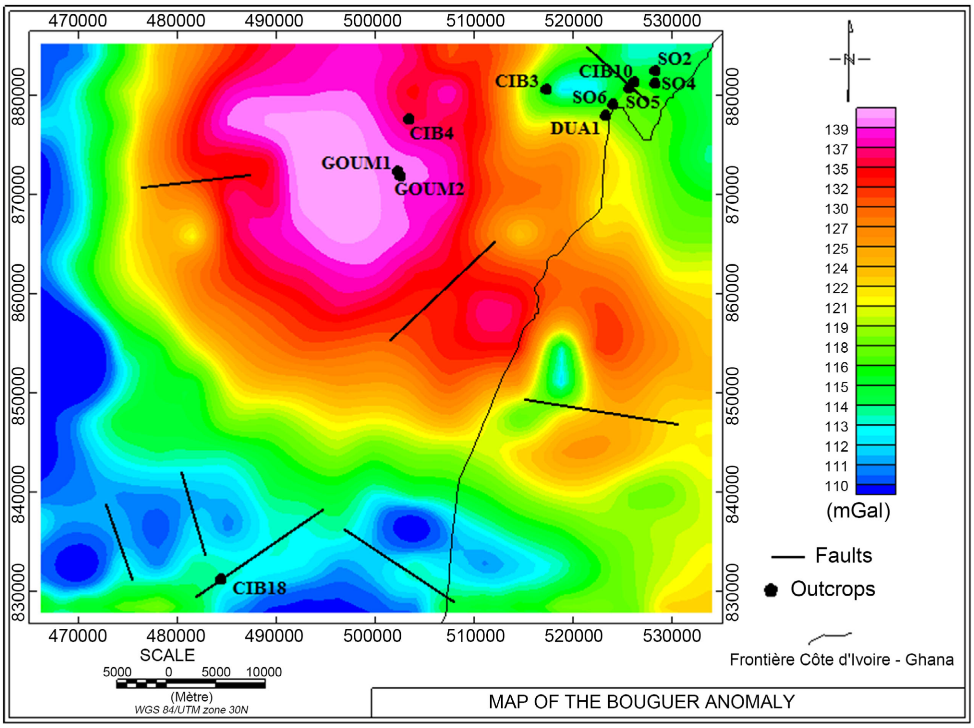
4. Results and Discussion

4.1. Lithological Study

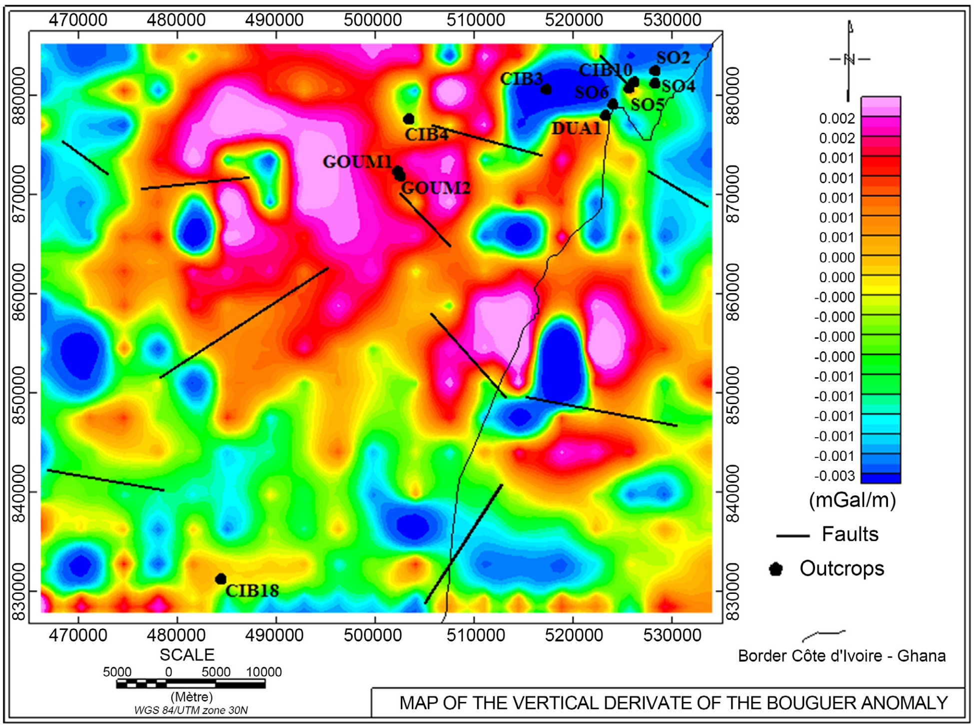
4.1.1. High-Density Lithological Facies

The Bouguer gravity anomaly map shown in **Figure 3(a)** and **Figure 3(b)** reveals the geological heterogeneity of the study area through color variation. Depending on the color scale, Bouguer anomaly amplitudes range from 110 to 139 mGal. Regions of high density (anomalies with amplitudes above 121 mGal and colors ranging from orange-yellow to magenta) are the most dominant. The relatively rounded shape suggests the existence of a major massive intrusive dominating the region. Approaching the sub-surface (**Figure 3(b)**), this important structure is well marked and extends as far as western Ghana. In the field, these high-density anomalies correspond to a series of formations composed of granodiorite (CIB10, GOUM1 and 2) and tonalite (CIB4), locally overlain by cinerites.

Macroscopic and microscopic descriptions indicate that this granodiorite is porphyroid and oriented. It has even been observed in the Soko locality to the northeast of the study area (**Figure 4(a)** and **Figure 4(b)**). Granodiorite is grainy in texture, with occasional enclaves of porphyritic metabasite and oriented amphibole minerals. The granodiorite is often altered in places, and sulfides have been identified in the metabasite.



(a)



(b)

Figure 3. (a) Bouguer anomaly map and (b) Bouguer anomaly vertical derivative map.

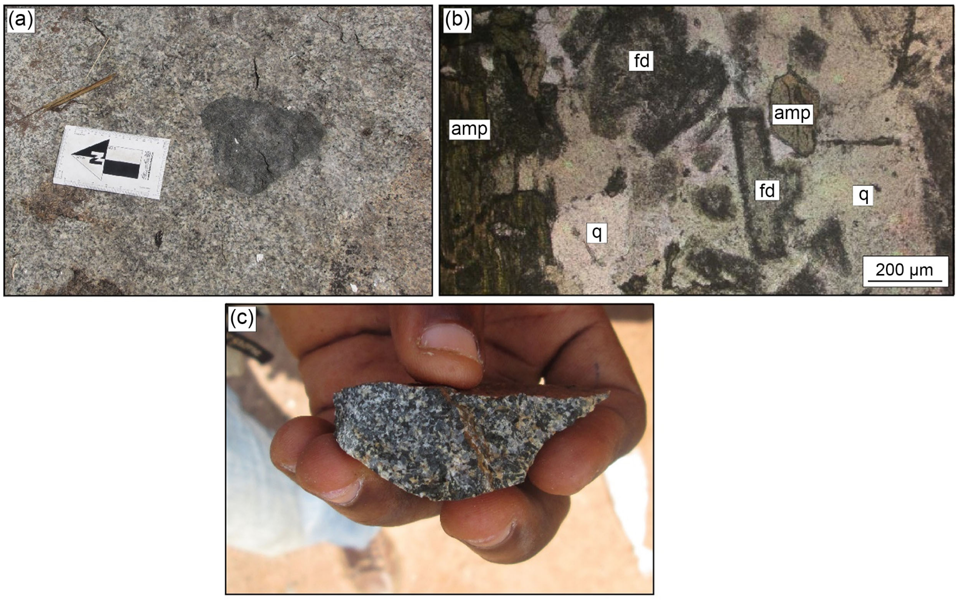


Figure 4. (a) fresh granodiorite with an enclave of metabasite; (b) microphotograph of thin slide CIB 10 of granodiorite; (c) photograph of tonalite observed at Gouméré. Fd: feldspar, q: quartz, amp: amphibole.

The tonalite observed in the Gouméré locality also has a grainy texture with a mesocratic color. It contains abundant feldspar minerals, amphibole and quartz (Figure 4(c)).

4.1.2. Low-Density Lithological Facies

On the gravity maps (see Figure 3(a) and Figure 3(b)), the cold color anomalies (blue) highlight all low-density formations. On the map of the vertical derivative (dz) of the Bouguer anomaly (Figure 3(b)), the anomalies corresponding to this low density are observed to the west, south-west and north-east. Field and laboratory descriptions reveal a complex of Tarkwaïan formations (CIB3, CIB18, SO2, SO4, SO5) and associated formations (DUA1, SO6).

1) Tarkwaïan formations

- Polygenic conglomerates

These rocks have been observed on the Bondoukou-Appimadoum axis and outcrop in the form of a hill. The surface is altered, with boulders and healthy pebbles partly individualized by the passage of the road. This rock has also been observed on the Soko-Dua Kouamé axis. These conglomerates are also made up of quartz pebbles, rhyolite, quartzite, basalt (containing sulfides) and the presence of cinerite and deformed quartz veins (Figure 5(a)). In slide CIB 03, microscopic observation shows that the rock is composed of a granular-textured sandstone cement, made up of quartz, feldspar and other dark sedimentary grains (Figures 5(b)-(f)).

- Arkosic sandstone

These Tarkwaïan formations are vast in extent. In the field, they occupy almost the entire study area. They have been mapped along the Gouméré-Dadiassé axis, then around 300 m from Koun-fao, towards Tanda (CIB 18, Figure 6(a)). These rocks are composed of abundant quartz, sometimes in pebbles or large grains of variable size, less than 5 cm. As a result, they can be assigned microconglomeratic facies levels (Figure 6(b)). Next, there is a notable abundance of finer grains of orthoclase, giving these formations a pink color. This is metaarkose. The latter forms the cement in the micro-conglomeratic levels (Figure 6(b)). In places, quartz-like formations are encountered, with fine, dark interlocking beds of biotite and ferro-titanium oxides (magnetite, hematite, ilmenite) and/or sulfides. This is the effect of gneissification due to metamorphism. These formations can be described as grauwackes (Figure 6(c) and Figure 6(d)).

2) Associated formations

Like the Tarkwaïan formations, the low-density anomalies are also described by the presence of volcanics composed of tuffs and cinerites (Figure 6(e) and Figure 6(f)).

Tuffs (DUA1) are also observed at Dua-kouamé (north-east of the study area). They present stratified levels with vertical granoclassing containing quartz pebbles and fine sediments. They show no trace of deformation (Figure 6(e)).

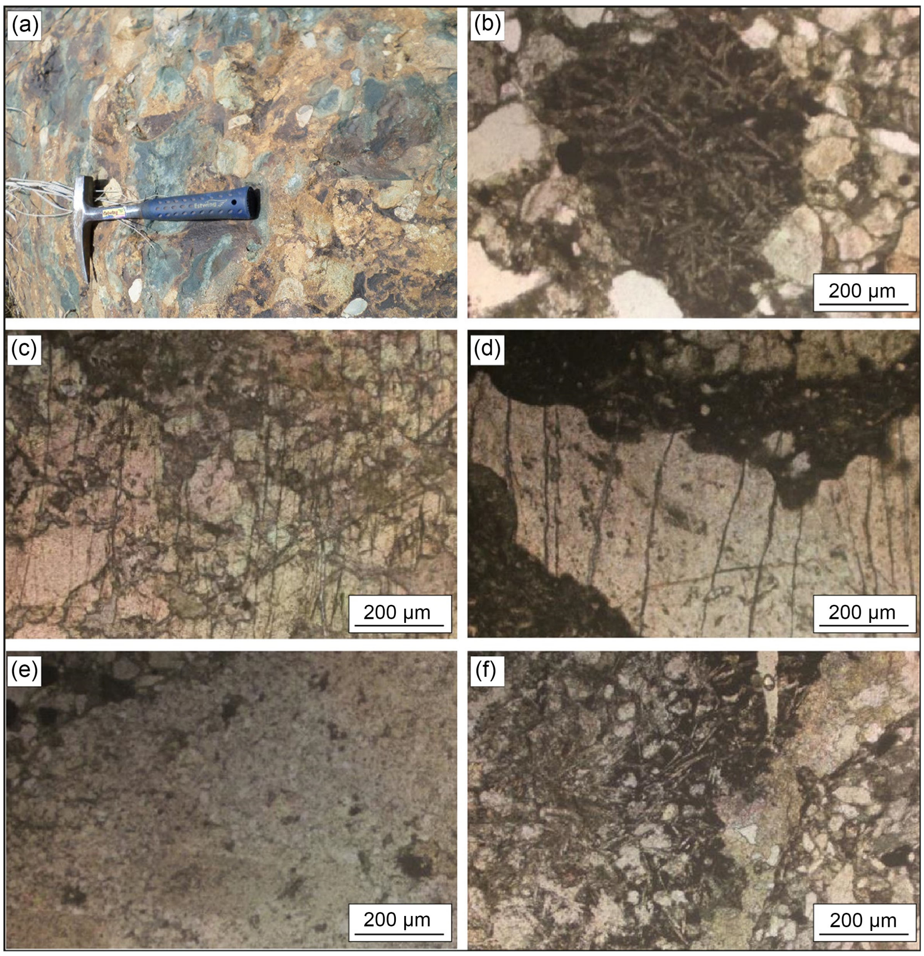


Figure 5. (a) Photograph and (b, c, d, e and f) microphotographs of Bondoukou Tarkwaïen polygenic conglomerate from CIB 03, SO2, SO4 and SO5 thin sections.

Figure 6. (a and c) Photograph and (d) microphotograph of arkosic sandstone and greywacke from the Bondoukou Tarkwaïen; (b) quartz-pebble metaconglomerate with arkosic cement (e and f) Photographs of volcanic rocks associated with the Bondoukou Tarkwaïen; (e) tuff with visible quartz pebbles and vertical graded bedding; (f) Siago cinerite.

The kinerites were described in the field at Siago, a village located on the main Gouméré-Bondoukou road (see **Figure 1**). They form a contact with the polygenic conglomerate on the Bondoukou-Appimadoum axis. The rock has a slightly silicified appearance with a conchoidal fracture and a greenish-gray color (**Figure 6(f)**). Its texture is microlithic, with no apparent grain and a whitish-yellow ash appearance in the altered phase. There are two facies marked by variations in color intensity. Microscopically, cinerites have an oriented microgranular matrix and small colorless and whitish crystals.

4.2. Structural Study

The discontinuities and curvatures (see **Figure 3(a)** and **Figure 3(b)**) shown by the shape of the various Bouguer anomalies are indicative of the intense tectonic activity that has affected the region. Brittle and ductile structures can be distinguished. In the field, brittle structures are defined by fractures, faults and detachments. Ductile structures are marked by folds and schistosities.

4.2.1. Brittle Deformations

- Fractures

Several fracture networks have been observed in the arkose along the Gouméré-Dadiassé axis, running NNE-SSE, NE-SW, E-W, NW-SE (**Figure 7(a)**). These directions are clearly visible on the various interpreted gravity maps. Well-cleared fracture planes (fracture schistosities) have been observed in the Siago kinerite along the Gouméré-Bondoukou axis, trending from NW-SE to NE-SW with subvertical dips (**Figure 7(b)**).

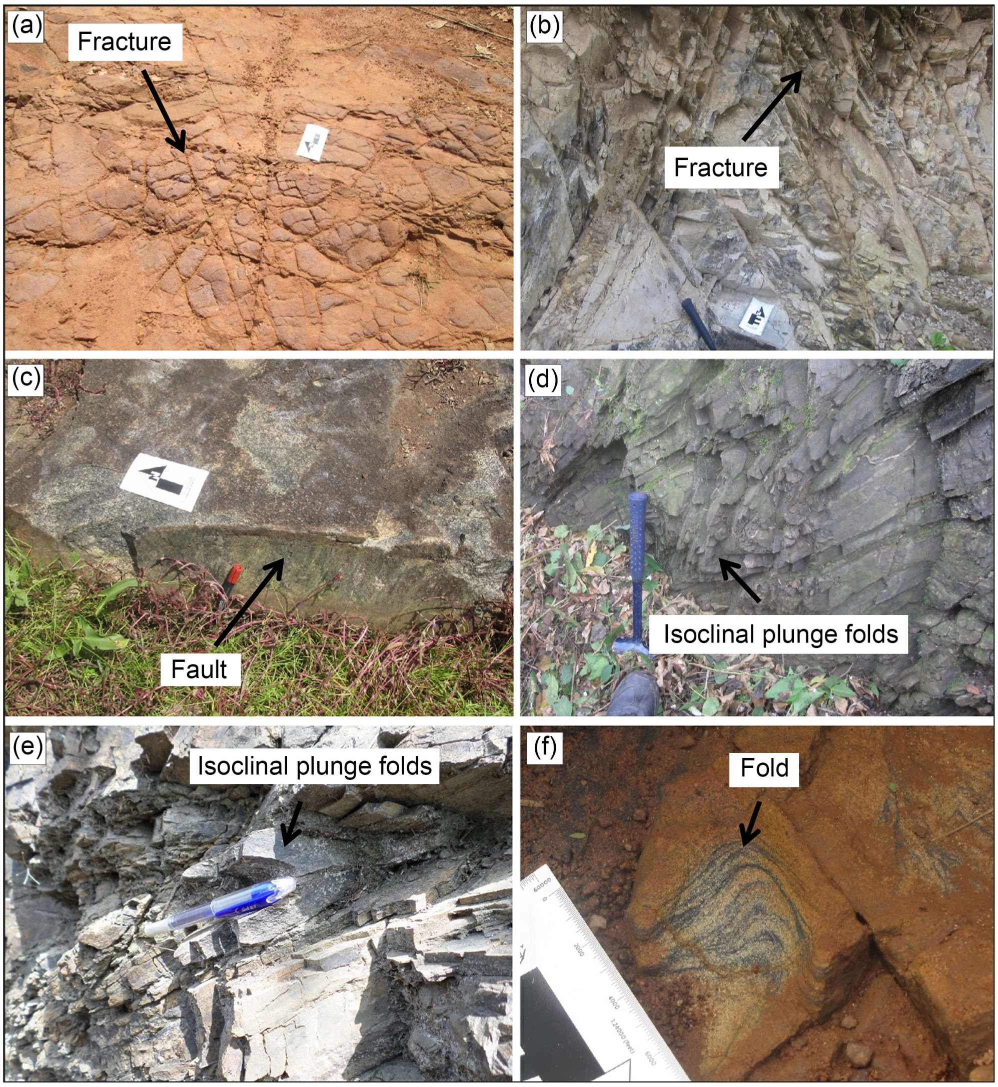


Figure 7. Photographs of brittle and ductile deformations in the study area. (a) Fracture network in the arkose; (b) Fracture planes in the Siago kinerite; (c) Faulting in the granodiorite; (d and e) Isoclinal plunge folds in the Siago kinerite; (f) Folding in the greywacke.3.3.

- Faulting and displacement

A fault has been observed in the Soko granodiorite. This fault shows a fault mirror with a plane of 64˚ towards WSW and striations plunging 70˚ towards NNW (**Figure 7(c)**). Several ENE to SSE conjugate fractures were encountered in the area, with NW-SE aplite veins. These fractures are probably evidence of a stall.

4.2.2. Ductile Deformations

- Schistosities

These structures were mainly observed in the arkosic microconglomerate with quartz pebbles and phyllite minerals, around 300 m from Koun-Fao on the Koun-fao-Tanda axis. The outcrop is a metaconglomerate with quartz and phyllite clasts oriented N10˚ and N166˚ (**Figure 6(b)**).

- Folds

Although not clearly identifiable on the various gravity maps, folds have been described in several formations in certain localities. In the Siago kinerite, for example, the folds observed are isoclinal and chevron-shaped (**Figure 7(d)**). The direction of the axial plane is N124˚, with a clear hinge axis dipping 40˚ towards SSW, observed in the vertical plane (**Figure 7(e)**). The direction of the axial plane is N124˚ with an axis dipping 40˚ towards SSW (**Figure 7(e)**). On the Gouméré-Dadiassé axis, the arkose is subvertically inclined in a NNW direction, folded by crenulation and dipping 64˚ to the NNE. The direction of the axial plane is N20˚. The grauwacke is also creased by crenulation. The direction of the axial plane is N20˚ (**Figure 7(f)**).

5. Discussion

5.1. Lithology

Gravimetric studies have shown that the Tarkwaïan formations (composed of polygenic conglomerates with grauwacke cement and arkosic sandstones) have been highlighted by low-intensity Bouguer anomalies (ΔBg < 114 mGal) (**Figure 3(a)** and **Figure 3(b)**). In terms of their extent, these formations are similar to those of the Kawéré series described by [2] [13] in Ghana and Burkina-Faso [16]. In the region, Tarkwaïan formations cohabit with volcanics (tuffs, cinerites) and intrusive rocks (tonalites, granodiorites). The intrusive formations are described on gravity maps by high-intensity anomalies (ΔBg > 121 mGal) (see **Figure 3(a)** and **Figure 3(b)**). Granodiorites have also been described by [11] [13] [17] in Ghana. The presence of the sulphide minerals described in this work reveals that the Tarkwaïen of Côte d'Ivoire is well mineralized, with a style of gold mineralization similar to that of neighboring Ghana [10].

5.2. Structural

The various structural studies carried out on the basis of gravity maps and macroscopic and microscopic observations of rock samples have shown that the different lithologies studied are affected by brittle and ductile deformation.

Based on structural data of [5] assert that Birimian and Tarkwaian rocks were jointly deformed during a single progressive deformation event. Similarly, the presence of NNE-SSE, NE-SW, E-W and NW-SE fracture networks and folds appearing as subhrizontal crenulation observed in the study area would correspond to the structures of the D5 deformation phase described by [13]. [13] also mentions a D3 phase that appears in the form of subvertical crenulation. This D3 phase would be responsible for setting up the folds observed in the arkoses whose axial plane is N20˚. The direction of the fold axes described at Siago is consistent with D3 deformation, followed by a quasi-orthogonal deformation phase, which would be the late shortening phase described by [10]. These large WNW-ESE fold structures and the schistosity affecting the Koun-Fao microconglomeratic series can be traced back to a post-Eurnaean regional shortening, oriented NNE-SSW, followed by a sinister detachment noted on the sigmoidal forms. The work of [16] in Burkina-Faso argues that Tarkwaïan deposition in the final phase of D1 deformation (2120 - 2110 Ma) is contemporaneous with a phase of E-W transtension/extension, preceded by WNW-ESE compression with isoclinal folds and the emplacement of shear zones during regional metamorphism. The 2012 activity report for the Tarkwa mine in Ghana (http://www.goldfields.co.za) reports shear zones that mark the contact between the Birimian and Tarkwaian and contain gold mineralization. This agrees well with the large, angular and deformed quartz grains observed at Koun-Fao and Gouméré in the sedimentary matrix.

6. Conclusion

The studies carried out in the Gontougo region (North-East) focused on the geophysical and petro-structural characteristics of the Tarkwaïen and associated formations. Interpretation of gravity maps showed that the Tarkwaïan formations (polygenic conglomerates, greywacke, arkosic sandstones) and volcanics (tuffs, cinerites) are of low density ($\Delta Bg < 114$ mGal). These lithological formations are intruded by denser granodiorites and tonalites ($\Delta Bg > 121$ mGal), which are highly representative on the gravity maps studied. These different lithological facies are strongly affected by brittle and ductile deformation, mainly oriented NNW-SSW, WNW-ESE and NE-SW. The description of the sulphide minerals is indicative of a style of gold mineralization in the Tarkwaïan formations.

Conflicts of Interest

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

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