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(Research Article)

Petro-structural characteristics of the Tarkwaian and associated formations in the Bondoukou area (Northeastern Côte d'Ivoire): Implications for the Paleoproterozoic evolution of the West African craton

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Abstract

The Tarkwaian formations, well known in Ghana for their gold-bearing potential, also outcrop in northeastern Côte d'Ivoire, particularly in the Bondoukou area. This study aims to characterize the petrographic and structural features of these formations and their associated volcanic and intrusive rocks, in order to contribute to the understanding of the Paleoproterozoic evolution of the West African craton. Fieldwork, macroscopic and microscopic petrographic analyses (seven thin sections), and structural measurements were carried out. The results show that the Bondoukou Tarkwaian consists of polygenic meta conglomerates (quartz, basalt, andesite, rhyolite, dolerite, schist pebbles) in a greywacke matrix, meta-arkoses, and greywackes with oxide laminations. Associated formations include volcanics (tuffs, deformed cinerites) and intrusive rocks (tonalite, oriented porphyritic granodiorite with mineralized metabasite enclaves). Structurally, these rocks record multiple brittle (N98° to N166° fractures, faults) and ductile (chevron isoclinal folds, cleavage, mineral lineations) deformation phases. The main orientations (NW-SE to NNE-SSW) are interpreted as resulting from Eburnean and post-Eburnean shortenings. The occurrence of mineralized metabasite enclaves and pebbles suggests a metallogenic potential similar to Ghanaian paleoplacers. This study confirms that the Ivorian Tarkwaian was emplaced in a shortening (tightening) context and represents a lateral equivalent of the Ghanaian series.

Keywords: Tarkwaian; Petro-Structural; Paleoproterozoic; Bondoukou; Côte d'Ivoire; West African Craton

1. Introduction

The West African craton, and particularly its Man Ridge, records a complex geological history from the Archean to the Paleoproterozoic. The Baoulé-Mossi domain (Paleoproterozoic) is characterized by Birimian greenstone belts and Tarkwaian sedimentary basins, the latter being famous in Ghana for their gold paleoplacers [1,2]. In Côte d'Ivoire, outcrops attributed to the Tarkwaian exist in the Bondoukou region (Northeast), but they have been the subject of few detailed studies, especially from a petro-structural perspective [3,4].

Understanding the petrographic and structural characteristics of these formations is essential not only for reconstructing the geodynamic evolution of the West African Paleoproterozoic but also for evaluating their metallogenic potential, by analogy with Ghanaian deposits. This work aims to: (1) precisely describe the lithology of the Tarkwaian and associated formations in the Bondoukou area; (2) characterize the deformation structures (brittle and ductile) affecting them; (3) discuss their implications for the Eburnean history.

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2. Geological setting

2.1. General framework: the West African craton

The West African Craton (WAC) constitutes one of the main Archean to Paleoproterozoic nuclei of the African continent (Figure 1). It is bordered by Pan-African belts (Mauritanides, Rokelides) and Neoproterozoic to Phanerozoic sedimentary basins (Taoudéni, Volta, Tindouf) [1,2]. Two main ridges compose the WAC: the Réguibat ridge in the northwest and the Man-Léo ridge in the southwest. Recent work on the Réguibat ridge has highlighted the existence of a new orogen, the Tiris orogen (2.51–2.46 Ga), which played a key role in the final assembly of the Archean craton before its incorporation into the Eburnean accretionary orogen [4]. The collision with the Eburnean orogen (ca. 2.07–2.03 Ga) was controlled by thermal erosion and softening of the cratonic margin, allowing the propagation of a thrust system towards the craton [4]. The Man Ridge is subdivided into two distinct domains separated by the north-south Sassandra fault:

An Archean domain (west): aged 3.6 Ga to 2.7 Ga, corresponding to the Leonian (3.4–3.0 Ga) and Liberian (2.9–2.7 Ga) cycles. It consists of migmatites, granulitic gneisses, greenstone belts and TTG intrusions [5,6].

A Paleoproterozoic domain (east): also called the Baoulé-Mossi domain (2.5–2.0 Ga), formed during the Eburnean orogeny. It includes Birimian greenstone belts (metavolcanics, metasediments) and Tarkwaian sedimentary basins (conglomerates, sandstones, arkoses, quartzites) [7,8]. The entire craton stabilized around 1.6 Ga [9].

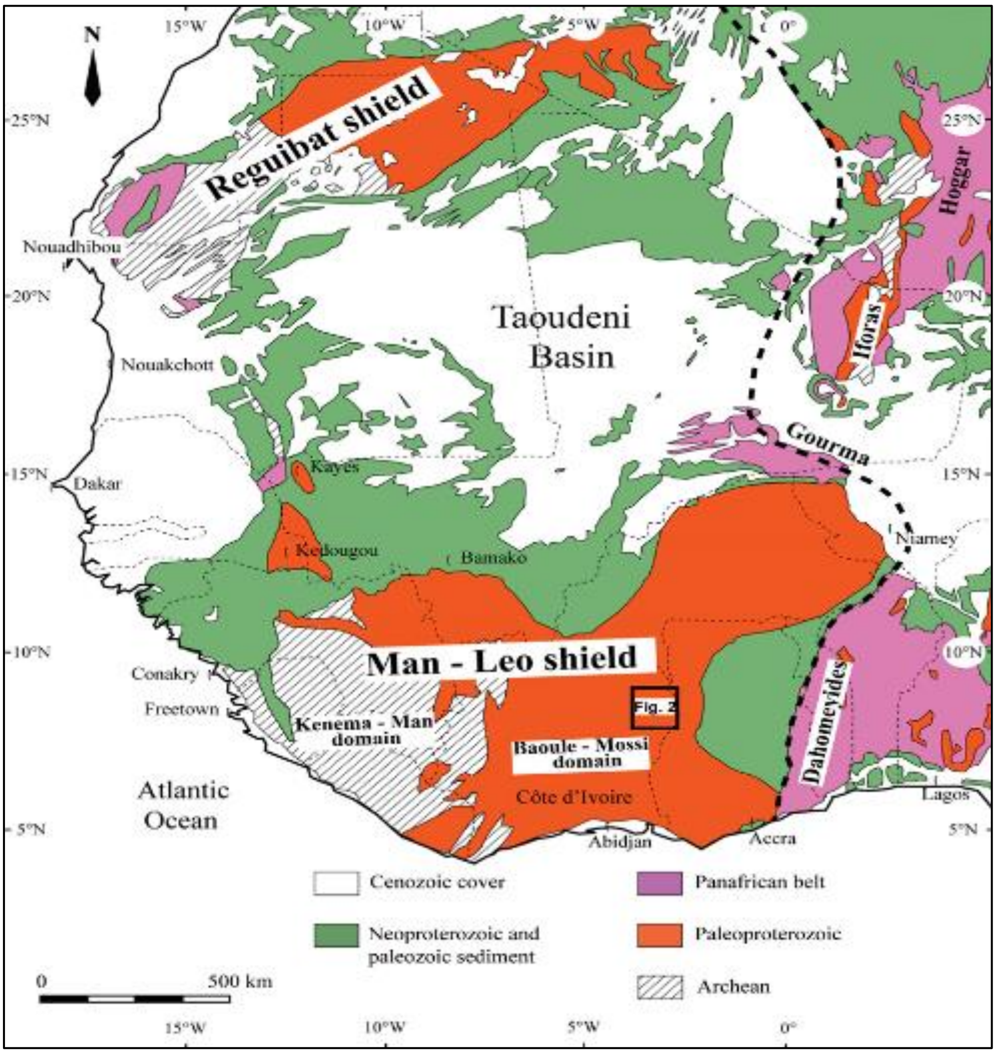

Figure 1 Geological sketch map of the West African Craton, adapted from [5, 10,11,12, 13, 14, 15, 16, 17, 18, 20]

2.2. Geology of Côte d'Ivoire

Côte d'Ivoire occupies the southern part of the Man – Leo Shield. The Precambrian basement covers 97.5% of the territory, with a narrow coastal sedimentary basin (Cretaceous–Tertiary) in the far south [20]. Two main domains are distinguished (Figure 2):

- Archean domain (west): outcrops west of the Sassandra fault (Man, Danané, Biankouma massifs). It is composed of gneisses, migmatites, charnockites, amphibolites and ultrabasic rocks. Dating gives Leonian (3.4–3.0 Ga) and Liberian (2.9–2.7 Ga) ages [5,21].
- Paleoproterozoic domain (east): located east of the Sassandra, it corresponds to the Baoulé-Mossi domain (2.5–2.0 Ga). It is structured into several NNE-SSW oriented Birimian volcano-sedimentary belts (Ferké, Dimbokro, Bondoukou, etc.) [22]. These belts are bordered or cut by syntectonic (Baoulé type) and post-tectonic (Bondoukou type) granitoids [18]. Regional metamorphism reaches greenschist to locally amphibolite facies.

The transition zone, located north of the SASCA domain (Sassandra-Cavally), is characterized by the presence of Archean relics within the Paleoproterozoic domain, indicating crustal contamination during Eburnean accretion [23].

2.3. Local geological context: Bondoukou area

Our study area is located in northeastern Côte d'Ivoire, about 416 km northeast of Abidjan, around the town of Bondoukou (Figure 2). It lies within the Bui belt, a Paleoproterozoic greenstone belt that extends into northwestern Ghana [24]. It belongs to type II unit defined by Papon (1973) [25]., corresponding to shallow basins with acid/intermediate formations and volcano-sedimentary rocks.

Lithologically, we distinguish (Figure 3):

- Birimian formations (Paleoproterozoic): metavolcanics (basalts, andesites, rhyolites), metasediments (schists, phyllades), TTG and syntectonic granitoids (tonalites, biotite/hornblende granodiorites).
- Tarkwaian formations (subject of this study): they rest unconformably on the Birimian. They include polygenic conglomerates (quartz, basalt, andesite, rhyolite, schist pebbles), arkoses, greywackes and locally cinerites [26,27]. These outcrops occur as elongated hills.
- Post-tectonic intrusive: porphyritic granodiorite of Bondoukou type (dated at 2166 ± 49 Ma by Rb-Sr on whole rock), sometimes oriented, containing mineralized metabasite enclaves [15,22].
- Quaternary: lateritic duricrusts and recent alluvium.

Structurally, the region has been affected by the Eburnean orogeny (2.2–2.0 Ga) with several deformation phases (isoclinal folds, schistosity, fractures, shears). Previous work has highlighted the presence of alluvial gold mineralization associated with Tarkwaian conglomerates [9,20]. Recent work by Perret et al. (2025) [35] confirms that gold associated with shear zones in this region falls within the 2120–2095 Ma time window, corresponding to the peak of the Eburnean orogeny at craton scale [10]

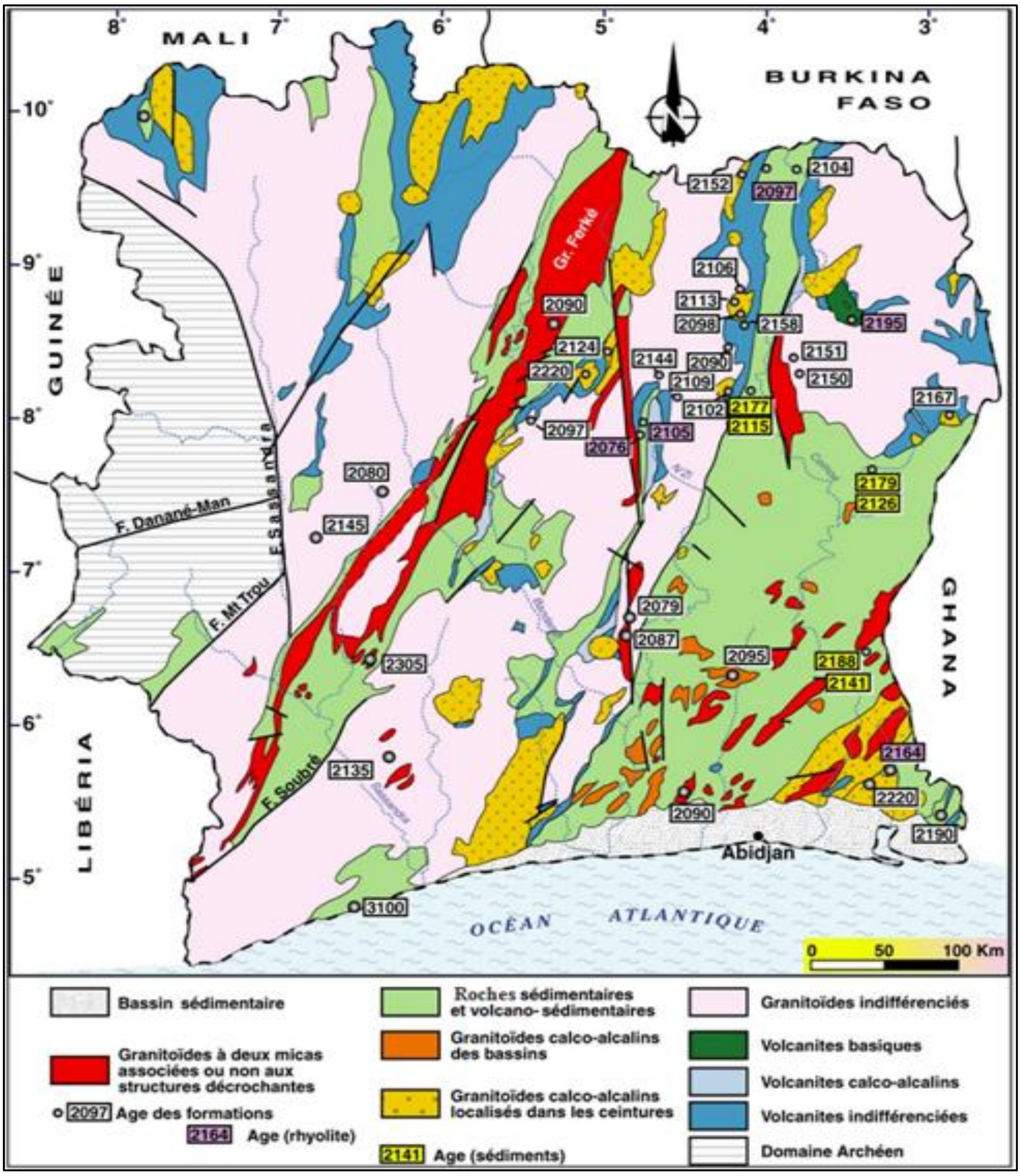

Figure 2 Simplified geological map of Côte d'Ivoire (modified after [6]).

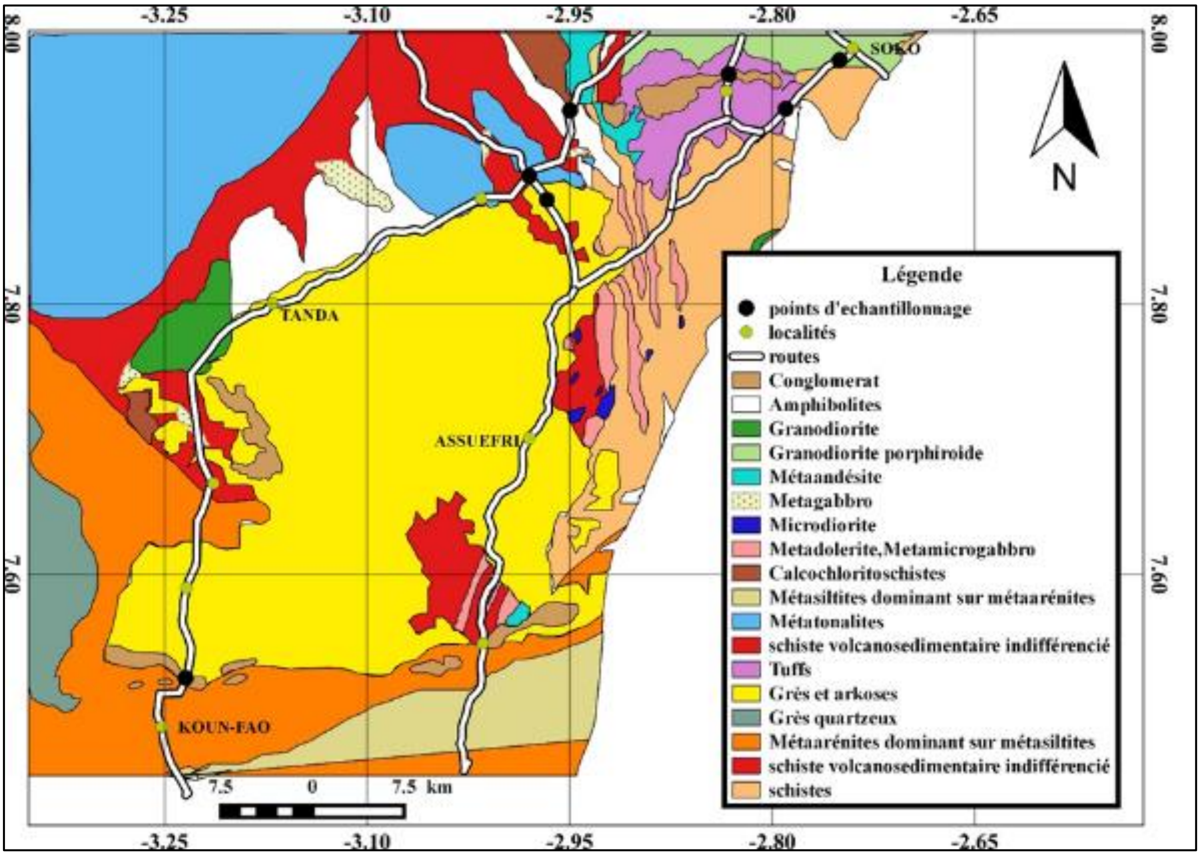

Figure 3 Local geological map of the study area [7]

3. Material and methods

Table 1 GPS coordinates of the main studied outcrops

Outcrop	Latitude (degree decimal)	Longitude (degree decimal)	Geographic location
Soko (SO1)	N 07.98555°	W 02.74295°	7 km East of Bondoukou
Dua-Kouamé (DUA1)	N 07.94259°	W 02.78901°	Dua-Kouamé Village
CIB 03	N 07.96663°	W 02.84281°	Bondoukou–Appimadoum Road
Siago (CIB 04)	N 07.93964°	W 02.96928°	Axe Bondoukou-Gouméré Road (Siago)
Gouméré (GOUM 1)	N 07.89192°	W 02.98000°	Gouméré Village
Koun-Fao (CIB 18)	N 07.51938°	W 02.23497°	Koun-Fao- Tanda Road
Soko-Ouest (SO5)	N 07.96731°	W 02.76774°	Soko-Dua Kouamé Road

The petro-structural study of the Bondoukou Tarkwaian is based on an integrated approach combining fieldwork, macroscopic and microscopic petrography, and detailed structural analysis. Fieldwork covered seven main sites (Soko, Dua-Kouamé, Appimadoum, Siago, Gouméré, Dadiassé, Koun-Fao, Tanda) based on existing geological maps (1/200,000) and satellite imagery. Systematic sampling collected fresh rocks, labeled and packaged. Structural surveys (Brunton compass-clinometer, precision ±1°) measured stratification, schistosity, lineations, fault planes, fractures and fold axes; GPS coordinates (Garmin) were recorded. Macroscopic descriptions (color, texture, structure, mineralogy, alteration, contact relationships) and outcrop photographs complemented the data. Seven thin sections (30 µm) were prepared at the LGSM laboratory (Félix Houphouët Boigny University) from representative samples (polygenic conglomerate, porphyritic andesite, greywacke, meta microconglomerate, cinerite, oriented granodiorite). Microscopic observation (Olympus BX51 microscope, LN and LPA, magnifications ×40 to ×400) allowed identification of mineralogy, textures, microstructures (undulous extinction, alignments), opaque minerals and metamorphic grade. Structural analysis processed oriented data via OpenStereo and StereoNett software (stereographic projections) to determine mean orientations, structural populations and kinematics (sigmoidal figures, conjugate fractures, stretching lineations, striations). Finally, digital mapping (MapInfo Professional 11.5) synthesized lithologies, structures, sampling sites and topography from previous work supplemented by field observations. Coordinates of key outcrops are reported in Table 1.

4. Results

4.1. Petrography

4.1.1. Tarkwaian formations

Polygenic conglomerate

The polygenic conglomerate outcrops mainly on the Bondoukou-Appimadoum axis, where it forms a hill. The superficial part is altered, but fresh blocks and individual pebbles are visible along the road (Figure 4a, b). A second outcrop, on the Soko-Dua Kouamé axis, presents both fresh and altered blocks as well as pebbles derived from the conglomerate itself, indicating a second generation of pebbles (Figure 4). The rock shows a "pudding" composed of pebbles of quartz, rhyolite, quartzite, basalt (locally with sulfides), associated with cinerite layers and deformed quartz veins.

Arkose sandstones and greywackes

The arkose and greywacke formations occupy a large extent in the study area, almost the entire mapped region. They were identified on the Gouméré-Dadiassé axis and about 300 m from Koun-Fao towards Tanda.

These rocks are characterized by abundant quartz, sometimes as pebbles or coarse grains of variable dimensions (generally < 5 cm), locally giving a microconglomeratic facies (Figure 5a). There is a notable proportion of fine orthose grains, giving a pinkish hue to the rock, typical of meta-arkose (Figure 5b). The meta-arkose constitutes the cement in the microconglomeratic levels. Associated with phyllite minerals, it takes on a purplish pink color, particularly visible on the Koun-Fao-Tanda axis (Koun-Abronso hills, Figure 5c). In places, quarzitic formations show fine dark cross-bedded laminae, interpreted as biotite and ferro-titanium oxides (magnetite, hematite, ilmenite). These facies, resulting from metamorphic gneissification, is termed greywacke (Figure 5d).

Two thin sections were made in these lithologies. One in the greywacke (GOUM 2, Figure 5a), the other in the highly metamorphosed sample from Koun-Fao (CIB 18, Figure 5b). The greywacke shows a fine granular matrix; very abundant quartz, showing undulous extinction characteristic of plastic deformation; beds of granular opaque minerals of medium size, associated with reddish to orange alteration (iron oxides) and micas, traversing the section; rare plagioclase, in medium-sized crystals. The highly metamorphosed sample from Koun-Fao shows extremely abundant quartz, of variable size, with undulous extinction; altered feldspars, subhedral, not very abundant, and a fine, clear matrix, indicating strong recrystallization.

These microscopic observations confirm the immature detrital nature of these sediments (high proportion of quartz, preserved feldspars) and record plastic deformation (undulous extinction) and greenschist-grade metamorphic recrystallization.

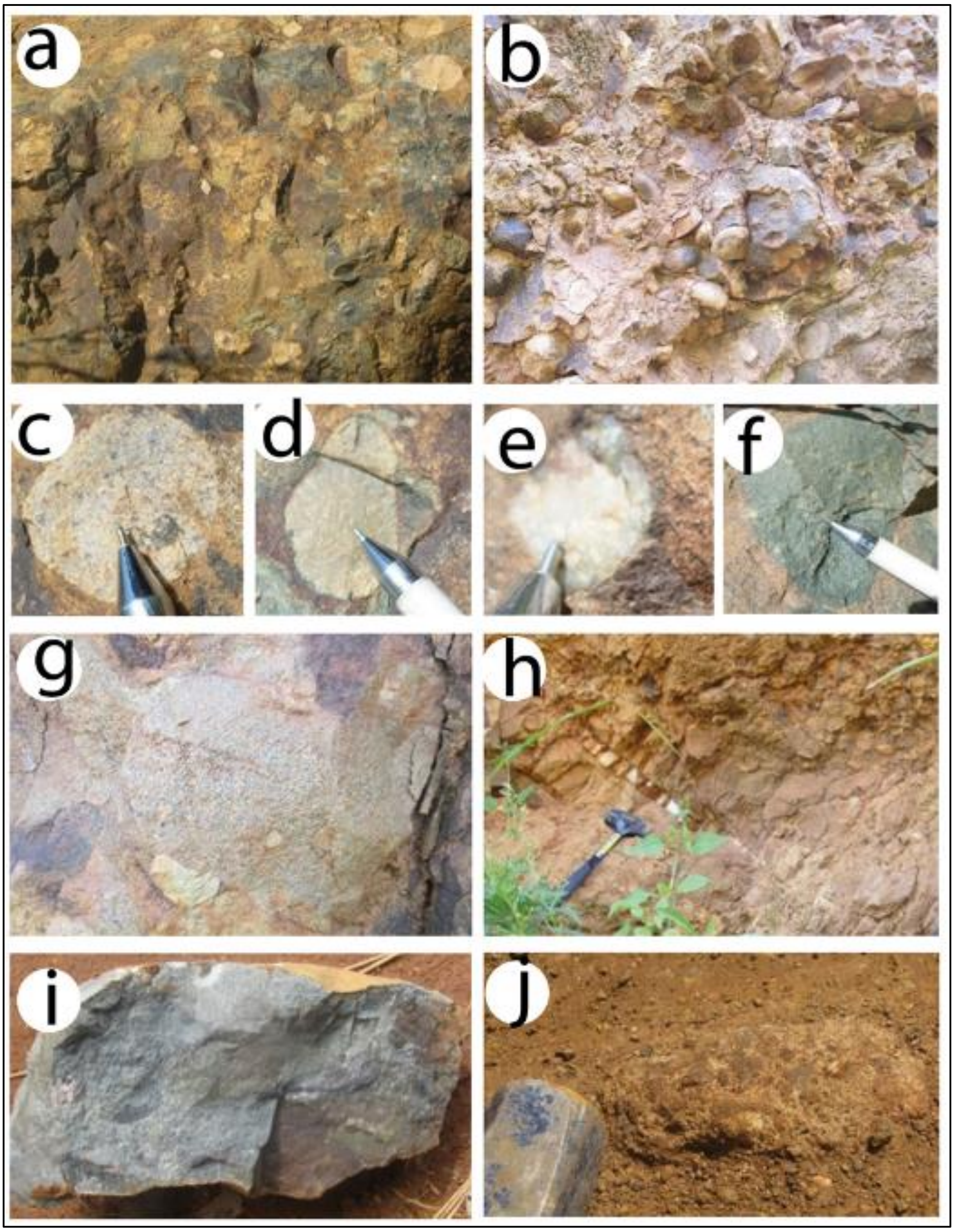

Figure 4 Photographs of the polygenic conglomerate of the Bondoukou Tarkwaian: (a) polygenic conglomerate; (b) rock pebbles embedded in a cement; (c) quartzite; (d) rhyolite; (e) quartz; (f) basalt; (g) presence of strata; (h) deformed quartz vein evidencing metamorphism and flattening; (i) fresh polygenic conglomerate; (j) weathered polygenic conglomerate.

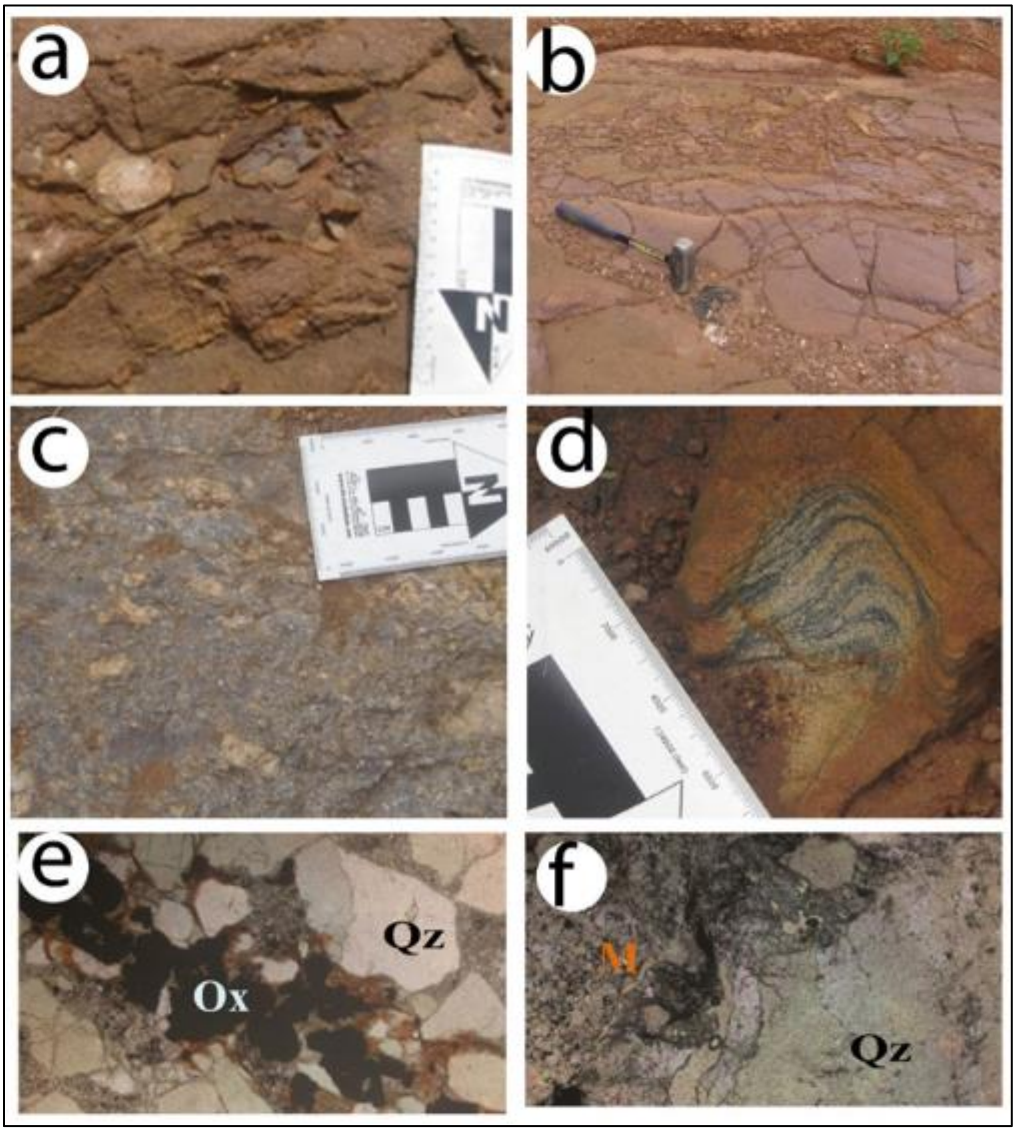

Figure 5 Photographs and microphotographs of sandstones, arkose and greywacke of the Bondoukou Tarkwaian: (a) quartz grains in the arkose; (b) meta-arkose; (c) meta conglomerate with quartz pebbles in arkosic cement with phyllite minerals; (d) greywacke; (e) greywacke with oxide bed; (f) meta microconglomerate. Qz: quartz; Ox: oxide; M: matrix.

4.1.2. Associated formations

These are represented by volcanics and intrusive. The volcanics consist of stratified tuffs with vertical grading (Dua-Kouamé); cinerites (Siago) with an oriented microgranular matrix, cut by several generations of fractures (Figure 6). Intrusive include a granular tonalite (Gouméré); an oriented porphyritic granodiorite (Soko) with zoned plagioclase phenocrysts, with quartz, amphibole, and mineralized metabasite enclaves (sulfides). The orientation of amphiboles (N100°) indicates syn- to post-magmatic deformation.

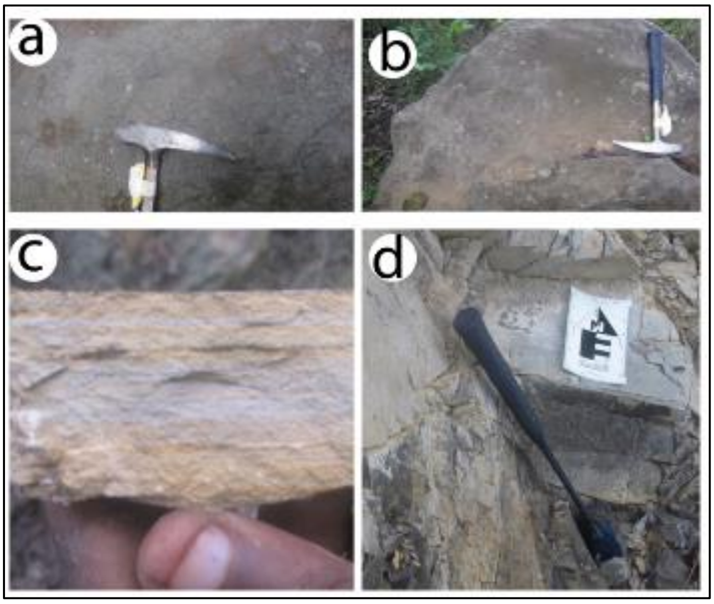

Figure 6 Photographs of volcanic rocks associated with the Bondoukou Tarkwaian: (a, b) tuff with visible quartz pebbles and vertical grading; (c, d) cinerite from Siago.

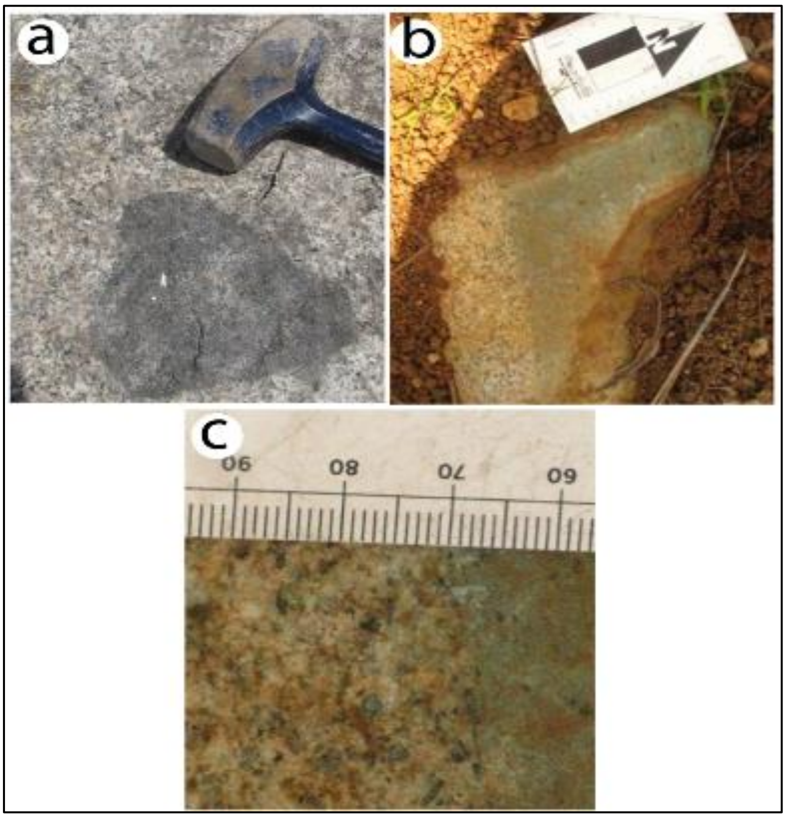

Figure 7 Photograph of the oriented porphyritic granodiorite. (a) fresh granodiorite with metabasite enclave; (b) contact between oriented granodiorite and metabasite; (c) phenocrysts in the granodiorite and in the metabasite enclave.

4.2. Structural features

The Tarkwaian and associated formations in the Bondoukou area are affected by several types of fractures (faults, strikes-slips) and ductile (folds, schistosity, lineations) deformations.

4.2.1. Brittle deformations

In the arkose outcropping on the Gouméré-Dadiassé axis, an oriented fractures network was measured. The directions recorded are: N98°, N166°, N90°, N58°, N68°, N10° and N20° (Figure 8a). Analysis of these orientations allows distinguishing three main fracture schistosity directions: NE-SW (N58° to N68°); E-W (N90° to N98°) and NW-SE (N166°). In the Siago cinerite (Gouméré-Bondoukou axis), well-defined fracture planes, akin to fracture schistosity, show directions from NW to NE, with subvertical dips. In the oriented porphyritic granodiorite of Soko, a fault mirror was identified. This plane dips 64° towards WSW. On this mirror, a mineral stretching lineation was measured, with a pitch of 70° towards NNW (Figure 8 c, d). This configuration (steep lineation plunge) suggests a dominant normal component, typical of an oblique normal fault or a strike-slip with a strong vertical component. Furthermore, several conjugate fractures were observed in the same area, with directions N82°, N112° and N176° (Figure 8b). Aplite veins, oriented N112° and N116°, are associated with these fractures (Figure 8a). The acute angle formed by the conjugate fractures (about 30° between N82° and N112°) indicates a principal stress direction σ_1 approximately N97° (E-W), consistent with regional shortening directions of the late phases of the Eburnean orogeny.

4.2.2. Ductile deformations

Folds were observed in several localities, with variable geometries and intensities. In the Siago cinerite, folds are isoclinal, chevron-shaped and en echelon (Figure 9a, b). The hinge is well exposed, the axis plunging, and the fold is observed in the vertical plane. The axial plane has a N124° direction (WNW-ESE) and dips 40° towards N214° (SSW). The fold axis is subvertical, oriented towards WNW. This geometry reflects strong flattening and superimposed deformations. In the arkose and greywacke, these rocks show crenulation folds. In the arkose, the subvertical NNO-trending strata are folded with an axial dip of 64° towards NNE; the axial plane direction is N20° (Figure 17c). In the greywacke, a sub horizontal crenulation affects the rock, with an axial plane also oriented N20° (Figure 9d). Schistosity and mineral lineations are particularly well developed in the arkose meta conglomerate with quartz pebbles and phyllite minerals outcropping about 300 m from Koun-Fao, on the Koun-Fao-Tanda axis. The outcrop shows quartz clasts and phyllites oriented along two major directions: N10° and N166°. The clasts show sigmoidal figures (Figure 9e). An elongation lineation marked by stretching of quartz grains is observed, as well as a crenulation lineation. This lineation is oriented N10° with a plunge of 20° towards N194° (SSW). A flow schistosity is also present: its plane is oriented WNW and dips 20° towards N194° (SSW) (Figure 9f).

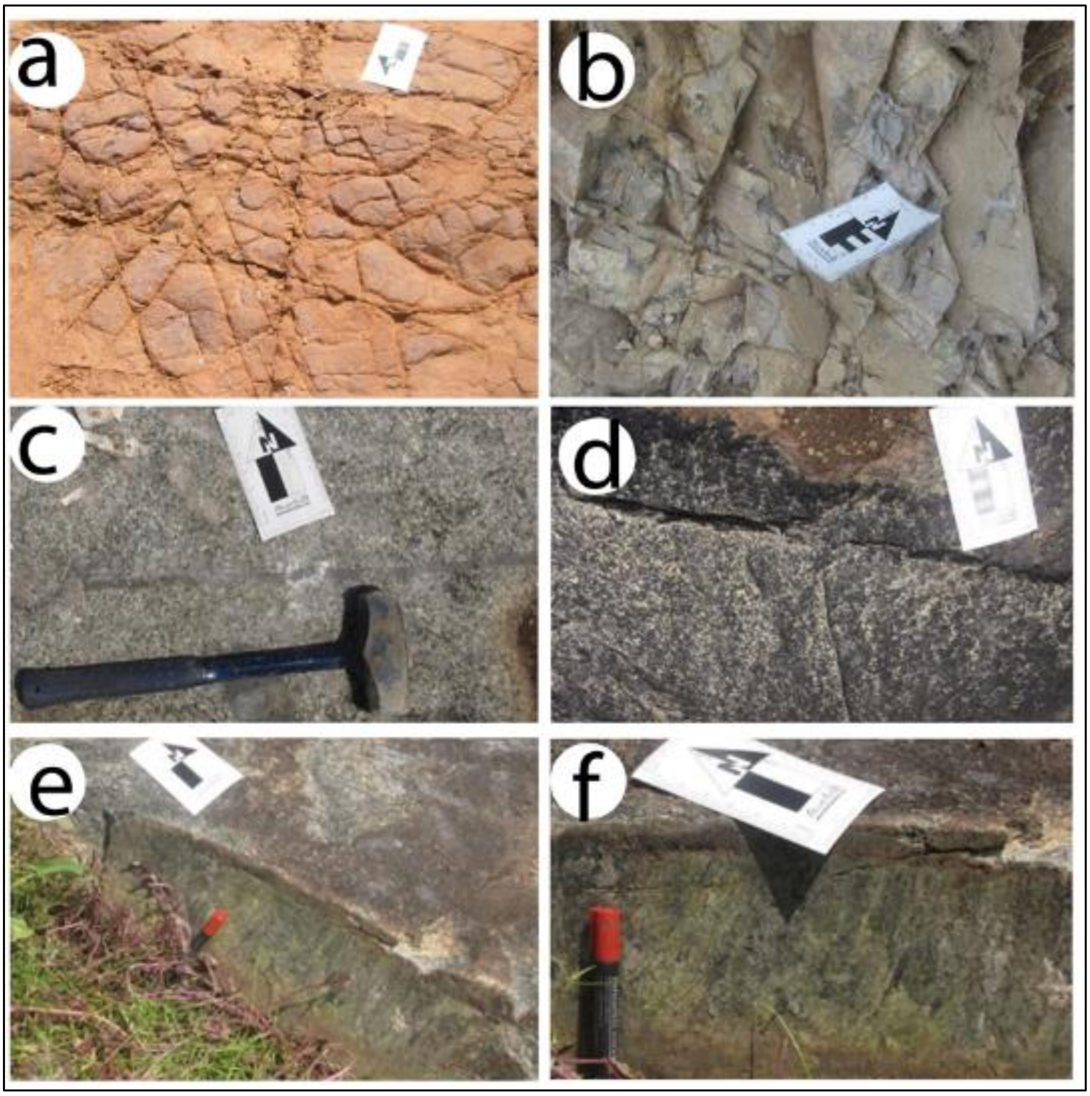

Figure 8 Photographs of fractures and faults observed in the study area. (a) fracture network in the arkose; (b) fracture planes in the cinerite at Siago; (c) aplite vein; (d) conjugate fractures; (e, f) mineral stretching lineation in the granodiorite.

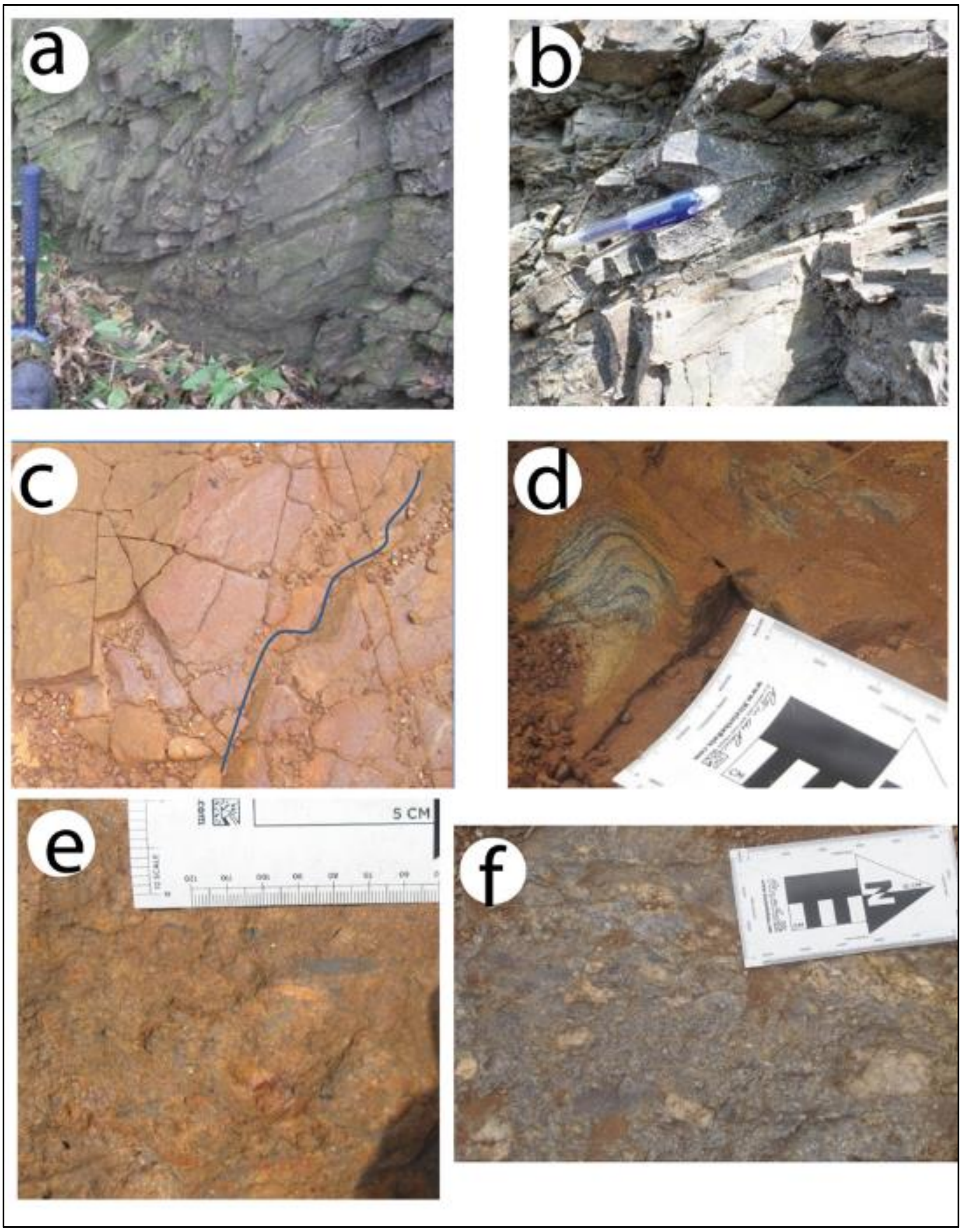

Figure 9 Photographs of folds, lineations and schistosity observed in the study area. (a) several en echelon isoclinal folds in the cinerite at Siago; (b) well-exposed hinge and plunging axis; (c) subhorizontal crenulation folds in the greywacke; (d) subvertical crenulation folding (fold axis N70, 50° towards ENE); (e) sigmoidal elongated phyllite minerals and relict figures; (f) differently elongated quartz grains (NE-SW and N-S) with dextral shearing.

5. Discussion

5.1. Lithological comparisons: originality of the Bondoukou Tarkwaian

5.1.1. A polygenic conglomerate contrasting with the Ghanaian model

Our macroscopic and microscopic observations indicate that the Bondoukou Tarkwaian consists of polygenic conglomerates with greywacke cement, containing pebbles of quartz, quartzite, rhyolite, mineralized metabasalts, andesites, dolerites and schists, as well as cinerite intrusions and deformed quartz veins. This lithological association resembles the Kawere series described in Ghana by Kitson (1928) [1] and Junner (1940) [28]. However, a major difference lies in the nature of the conglomerates: in Ghana, the Tarkwaian conglomerates (notably those of the Banket Formation) are monogenic, composed of more than 90% quartz pebbles, with siliceous cement [29]. At Bondoukou, the polygenicity of the pebbles (basalt, andesite, rhyolite, schist, etc.) indicates a more diversified source, directly derived from the erosion of surrounding Birimian rocks, notably the Sefwi Group. This facies difference can be explained by a more proximal position in the sedimentary basin or by lesser sediment reworking.

5.1.2. Arkosic and greywacke metasediments comparable to the Banket and Huni series

Our work reveals the presence of pinkish coarse-grained meta-arkoses (locally microconglomeratic) and greywackes with fine cross-bedded laminae of ferro-titanium oxides (magnetite, hematite, ilmenite). These lithologies evoke both the quartzites of the Huni Group [23] and the cross-bedded sandstones of the Banket Formation. The meta microconglomeratic level with quartz pebbles and phyllite minerals observed near Koun-Fao reinforces this analogy. Thus, the Bondoukou Tarkwaian presents a complete sedimentary sequence, ranging from coarse conglomerates (Kawere equivalent) to arkoses and greywackes (Banket and Huni equivalents), although typical phyllites (Tarkwa Phyllites) have not been clearly identified.

These results confirm and complement previous observations by Soulé-de-Lafont (1956) [24] in the same area, as well as work by Siméon et al. (1995) [7], who had already noted the presence of sandstones, arkoses and conglomerates with quartz pebbles on the Agnibilékrou sheet.

5.1.3. Comparison with the Tarkwaian of Burkina Faso

Baratoux et al. (2011) [17] described the Tarkwaian of Burkina Faso as a set of sandstones, quartzites, arkoses, phyllites and conglomerates with quartz, rhyolite and schist pebbles, weakly metamorphosed (Bossière et al., 1996) [30]. The Bondoukou Tarkwaian is similar in its low metamorphic intensity (greenschist facies) and the diversity of pebbles. However, a notable difference is the absence in Burkina Faso of significant gold mineralizations in the Tarkwaian, whereas Bondoukou presents alluvial gold indices and sulfide-bearing metabasalt pebbles, suggesting a metallogenic potential closer to the Ghanaian model.

5.1.4. Magmatic associations and geodynamic context

Recent studies at the scale of the West African craton shed additional light on the geodynamic context of the Bondoukou formations. On one hand, Chardon et al. (2024) [31] highlighted in the Réguibat shield the existence of a new orogen, the Tiris orogen (2.51–2.46 Ga), which played a key role in the final assembly of the Archean craton before its incorporation into the Eburnean orogen. The collision with the Eburnean orogen (ca. 2.07–2.03 Ga) was controlled by thermal erosion and softening of the cratonic margin, allowing the propagation of a thrust system towards the craton. This "hot" collision model could explain the late reactivation of structures in the Bondoukou zone, notably the dextral shears observed at Koun-Fao. On the other hand, a recent study on the provenance of Tarkwaian sandstones in the northeastern part of the Ashanti belt (Ghana) used petrography and geochemistry to constrain the nature of the sources [32]. The results indicate a dominance of felsic and metasedimentary magmatic sources, with a low degree of chemical weathering, compatible with an active margin setting. These conclusions are in perfect agreement with our observations on the arkoses and greywackes of Bondoukou, which show textural and mineralogical immaturity (high proportion of feldspars, angular grains) typical of proximal deposition in a compressive context.

Thus, the entire set of recent data supports the interpretation of the Bondoukou Tarkwaian being deposited in a foreland or intra-arc basin, linked to a mature subduction and a "hot" continental collision that reactivated late structures.

5.2. Structural interpretation: recording of Eburnean phases

5.2.1. Ductile and brittle deformations: markers of polyphase evolution

The structures observed in the Bondoukou Tarkwaian (poly directional fractures, chevron isoclinal folds, crenulations, flow schistosity, stretching lineations, sigmoïdal figures) testify to a polyphase deformation history, comparable to that documented in the Ashanti belt in Ghana [23] and in the Tarkwaian of Burkina Faso [17].

- Chevron isoclinal folds in the Siago cinerite (axial plane N124°, dip 40° towards SSW, subvertical axis). This geometry indicates strong flattening, characteristic of intense shortening phases (D3 according to Perrouty's nomenclature, [23]). Similar folds have been described in the Mako belt (Senegal) and interpreted as the result of WNW-ESE compression [33]

- Sub horizontal and subvertical crenulations in the arkoses and greywackes (axial planes N20°). These structures correspond respectively to phases D5 (sub horizontal crenulation) and D6 (subvertical crenulation) defined by Perrouty (2012) [23] in the Ashanti belt. They record the last stages of the Eburnean deformation, marked by a transpressional regime.
- Flow schistosity and stretching lineation in the Koun-Fao meta conglomerate (orientation N10°, plunge 20° towards SSW). These elements, associated with sigmoidal figures indicating dextral shearing, reveal a post-Eburnean regional shortening-oriented NNE-SSW. Siméon et al. (1995) [7] attribute these structures to the effect of large-scale regional folds, globally E-W trending, in agreement with our interpretations. Bonkoungou (1994) [34] described a similar structure in the Tarkwaian of the Houndé belt (Burkina Faso), noting a flattening component followed by a sinistral shearing phase.
- Poly directional fracture networks (NE-SW, E-W, NW-SE) and conjugate fractures (N82°, N112°, N176°) in the arkose and granodiorite. These fractures are interpreted as the result of successive tectonic reactivations, from early ductile phases to late brittle episodes. The acute angle of the conjugate fractures (about 30°) indicates a principal stress direction σ_1 approximately N97° (E-W), consistent with regional shortening.

5.2.2. Relative age of deformations and position of the Tarkwaian in the Eburnean cycle

The presence of pebbles of deformed rocks (notably porphyritic andesite CIB 03 bis) and deformed quartz veins in the polygenic conglomerate indicates that the Tarkwaian was deposited after the onset of Birimian deformation, and was itself affected by the late phases of the Eburnean orogeny. This is consistent with work by Eisenlohr and Hirdes (1992), who showed that Birimian and Tarkwaian rocks were jointly deformed during a single progressive deformation event.

Correlations with recent chronologies [35] allow specifying the position of the Bondoukou Tarkwaian in the Eburnean cycle:

- Deposition of Tarkwaian sediments would have occurred during the transition phase (c. 2135–2120 Ma) or at the beginning of the orogenic peak (2120–2095 Ma), after exhumation and erosion of Birimian rocks.
- Ductile deformation (isoclinal folds, schistosity) corresponds to phases D3 and D4 (2120–2095 Ma), contemporaneous with the metamorphic peak and main orogenic gold mineralization.
- Brittle deformations and late shears (D5, D6) are situated in the post-collisional interval (2095–2060 Ma), marked by a transpressional regime.

This interpretation is consistent with data from Perrouty (2012) [7] for Ghana (deposition of the Tarkwaian during D3) and with those of Baratoux et al. (2011) [17] for Burkina Faso (deposition during the final phase of D1, 2120–2110 Ma). The slight difference in phase nomenclature (D1 in Baratoux, D3 in Perrouty) reflects different scales of analysis, but the absolute ages are concordant.

5.2.3. The Koun-Fao zone: a sheared Tarkwaian-Birimian transition

The Koun-Fao outcrop, with its strong schistosity, pronounced lineation, sigmoidal figures and dextral shearing, presents characteristics similar to the shear zones marking the contact between Birimian and Tarkwaian in Ghana. The 2012 activity report of the Tarkwa mine (Goldfields) indicates that these shear zones are often gold-bearing. The structural similarity between Koun-Fao and these Ghanaian zones suggests a metallogenic potential to be explored. Siméon et al. (1995) [7] already noted that the Koun-Tanda series does not show internal penetrative deformations, but its southern border presents the manifest effects of epithermal tangential deformation, indicating that deformation is concentrated at lithological interfaces.

5.3. Metallogenic implications: towards a modified paleoplacer model?

The discovery of mineralized metabasite (with sulfides) as an enclave in the porphyritic granodiorite and as a pebble in the polygenic conglomerate is a major result of this study. This observation suggests that primary mineralization (probably gold-bearing, by analogy with Ghana) were present in the Birimian basement before the deposition of the Tarkwaian. Erosion of this basement then released mineralized clasts that were incorporated into the conglomerates, forming potential paleoplacers. Subsequent metamorphism and deformation may have partially remobilized these minerals, creating a "modified paleoplacer" model similar to that described by Pigois et al. (2003) [36] for the Tarkwa-Damang district in Ghana. Indications of alluvial mineralization (gold, cinnabar, manganese) have already been reported in the area by Siméon et al. (1995) [7] , in association with Tarkwaian sandstones and conglomerates. Our results support the hypothesis of an economic gold potential for the Bondoukou Tarkwaian, distinct from that of the Houndé Tarkwaian (Burkina Faso) known to be poorly mineralized (Bossière et al., 1996) [30].

6. Conclusion

This study shows that the Bondoukou Tarkwaian is lithologically diverse (polygenic conglomerates, arkoses, greywackes) and associated with deformed volcanics and intrusive. The recorded structures (fractures, folds, schistosity, lineations) result from several phases of Eburnean and post-Eburnean shortening (NW-SE to NNE-SSW). The presence of mineralized pebbles and sulfide-bearing enclaves opens perspectives for gold exploration. Geochemical, geochronological and metallogenic studies are necessary to constrain the age and genesis of these mineralizations.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no competing interests.

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