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Petro-structural characterization of geological rocks in the Soubré sector (Sassandra-Cavally domain, Southwestern Côte d'Ivoire)

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ABSTRACT: The Sassandra-Cavally (SASCA) domain (SW Côte d'Ivoire) marks the transition between the Archean Kenema-Man craton and the Paleoproterozoic Baoulé-Mossi domain. The methodology applied to study the rocks of the Soubré area considers both field and laboratory work. The Soubré area of the SASCA domain is characterized by migmatitic gneisses, metagranites and garnet micaschists. Migmatitic gneisses are composed of quartz, feldspar, biotite, chlorite, muscovite and opaque minerals, with occasional amphibole rods. Metgranites, on the other hand, are composed of quartz, feldspars such as plagioclase and microcline, biotite, accessory minerals and opaque minerals. Garnet-bearing micaschists are composed of quartz, biotite, muscovite, garnet, plagioclase with accessory and opaque minerals. Structural observations in the Soubré area reveal a first foliation (S1) trending NW-SE, dipping between 40° and 85° towards SW and associated with a N080-trending shear with a sinistral component, as well as folds whose axial planes are parallel to S1. This first foliation is intersected by a second (S2) trending NE-SW with dips of 60-85° either towards NW or SE. The S2 foliation is associated with a N166 shear with a sinistral component and folds whose axial planes are parallel to S2. All these structural observations in the Soubré sector would be compatible with the structures observed in the SASCA domain on the coast from Grand-Béréby to Tabou.

KEYWORDS: Petrography, analysis structural, Sassandra-Cavally domain, Soubré.

1 INTRODUCTION

The Sassandra-Cavally (SASCA) domain (named according to the two rivers that run across the area) represents a contact zone between the Archean and Paleoproterozoic domains of the West African Craton in the South-west Côte d'Ivoire [1–4]. This domain is mainly built of migmatitic grey gneisses commonly intercalated with amphibolites and metasediments, also locally migmatitic. In the southern most part (region of Tabou), diopside- and hypersthene-bearing metabasic granulitic gneisses predominate [5]. These lithological units are intruded by granites, granodiorites, syenites, as well as associated aplites and pegmatites [6], and crosscut by large ductile structures such as the Greenville-Ferkessédougou-Bobo-Dioulasso shear zone [7,8].

Recent work by Koffi et al. (2023) [9] from Grand-Béréby to Sassandra mentions three main deformation phases (D1-D3) in the SASCA domain. The first phase, D1, is characterized by NW-SE-trending, subvertically dipping S1 penetrative foliations with the presence of tight isoclinal folds whose axial planes are parallel to this foliation. D1 is interpreted as a NE-SW shortening. Phase D2 features subvertically dipping, NNE-SSW-trending S2 metamorphic foliations with tight to open folds whose axial planes are parallel to S2, as well as sinistral ductile shear zones. The L2 lineation is parallel to the fold axes and dips between 30° and 80° towards NNE. D2 is interpreted as a continuous NNW-SSE shortening as part of a transpressive regime. Finally, phase D3 is expressed by a penetrative S3 E-W schistosity associated with E-W-trending dextral shear zones suggesting WNW-ESE shortening. Structural and microstructural studies carried out in the Gbowé sector of Grand-Béréby define D1 and D2 phases marked by NE-SW and NW-SE flattening respectively, followed by a D3 phase characteristic of brittle deformation [10]. Field observations from Grand-Béréby to Sassandra conclude that the tectonic evolution of the SASCA domain is marked by a model in which crustal thickening is achieved by crustal-scale folding, followed by lateral flow of thickened, partially melted crust accommodated by transcurrent regional shear zones [9]. Do these field observations in other areas of the SASCA domain support such a conclusion or not ? Hence the pre-structural study of the Soubré area formations.

This study is intended to contribute to a better understanding of the petrography and structural features of the Soubré sector, and more specifically to a better contribution to the tectonic evolution of the Sassandra-Cavally domain.

2 GEOLOGICAL SETTING

Côte d'Ivoire belongs to the West African Craton and more specifically to the Leo-Man Shield [11]. In the Leo-Man Shield, the Archean domain is called Kenema-Man while the Paleoproterozoic domain to the east is known as the Baoule-Mossi domain [11]. The Archean Kenema-Man domain consists of two main complexes: a basal complex consisting of migmatites and granulitic gneisses unconformably overlain by a sequence of supracrustal rocks deformed and metamorphosed at 2800 ± 20 Ma [1,12–15]. The basal complex is intruded by various plutonic rocks including granite, granodiorite, charnockite, as well as basic and ultrabasic rocks dated around 2.8 Ga [2,13,15,16].

Deformation in the West African Craton, more precisely in the Baoule-Mossi domain, is characterized by horizontal shortening leading to crustal thickening, followed by transcurrent tectonics forming regional shear zones [8,17–29]. This reflects a complex polycyclic structural evolution in the West African Craton [8,24,26,28–30].

This polycyclic structural evolution can be observed across several regions of the West African Craton: in western Burkina Faso, three tectonic events (D1-D3) characterized respectively by compression, shearing as well as thrust faults have been identified [8]; in northern Ghana, the work of Block et al. (2016) [28] indicates seven deformation phases (D1-D7) characterized by compression with an extensional phase that generate shear zones; in southern Ghana in the Paleoproterozoic Sefwi greenstone belt, McFarlane, (2018) [29] highlights several deformations (D1-D5) including a D2 phase that is globally transtensional with senestial play leading to rock exhumation; Caby et al. (2000) [31] observe a juxtaposition of three domains in the Paleoproterozoic formations of the Odienné region in Côte d'Ivoire, which is due to essentially senestial horizontal downward movements along a shear zone; finally, recent work carried out from Grand-Béréby to Sassandra in Côte d'Ivoire mentions three main deformation phases (D1-D3) [9]. However, the work of Vidal et al. (1996) [32] and Pouclet et al. (1996) [33] suggests peri-Plutonic deformation with "archaic" mechanisms marked by intrusions, collages and lateral displacement of crustal blocks. Later, sagduction-type vertical tectonics followed by horizontal tectonics in "warm and soft" Paleoproterozoic lithospheric conditions were mentioned by Vidal et al. (2009) [25], Lompo (2010) [26].

Metamorphism is typically characterized by regional greenschist facies conditions [34–36], but locally reaches amphibolite facies or even granulite facies metamorphism [9,37,38]. LA-ICP-MS U-Pb dating of monazite from southwest Côte d'Ivoire in the SASCA domain reveals four metamorphic age groups: (1) ~2400-2600 Ma; (2) ~2037 Ma; (3) ~2000 Ma and (4) ~1978 to 1913 Ma documented for the first time in monazites from the West African Craton [9].

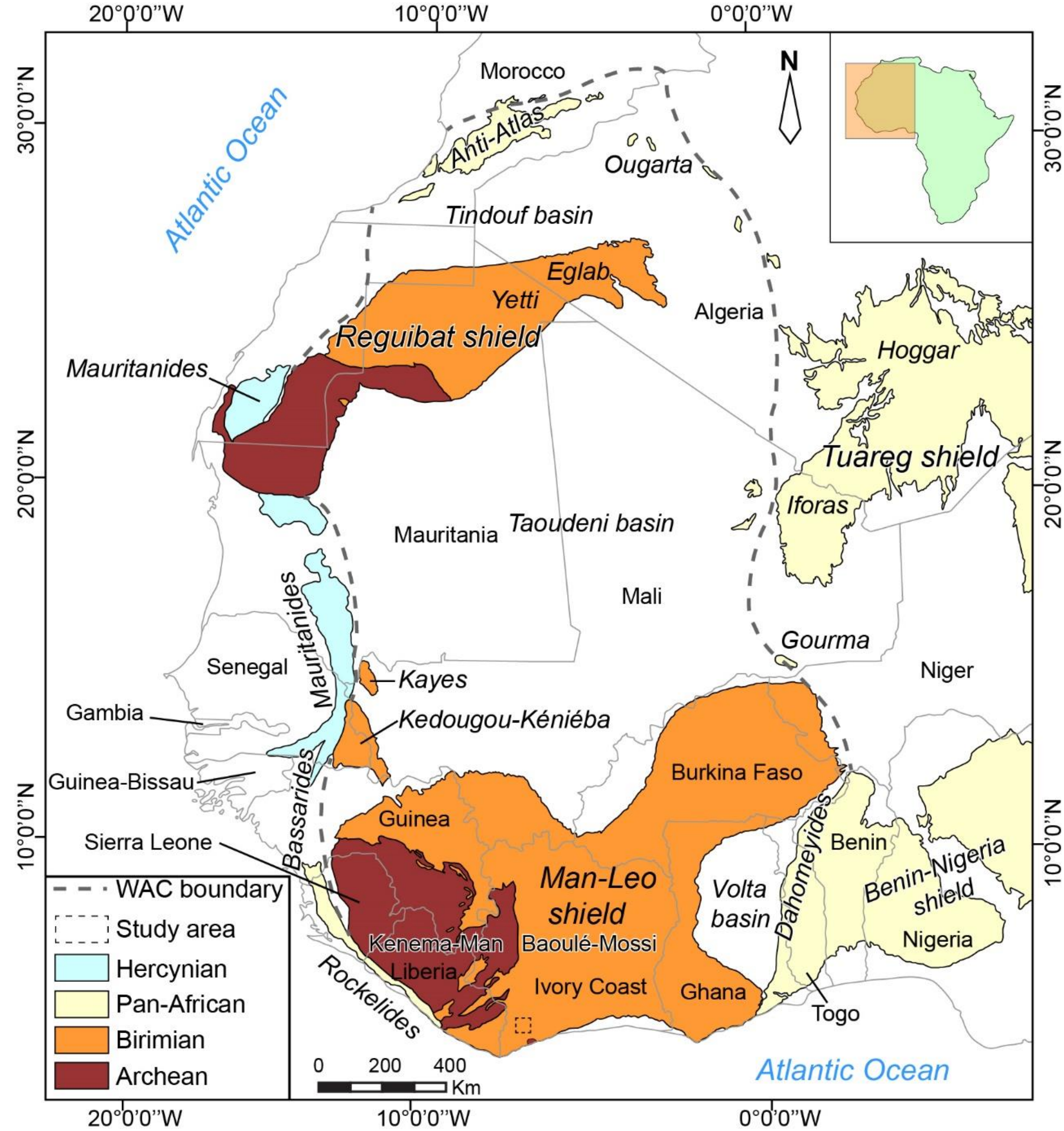


Fig. 1. Geological sketch map of the West African Craton (modified after the BRGM SIG Africa map and Ennih and Liégeois, 2008 [39]; Berger et al., 2013 [40]; Thiéblemont, 2016 [41]). The position of the present-day margins of the craton is constrained by geophysics [42].

3 METHODOLOGY

The methodology applied to study the rocks of the Soubré area takes into account both field and laboratory work. Methods have been developed for each of these stages.

3.1 MACROSCOPIC AND MICROSCOPIC PETROGRAPHY

Macroscopic petrography is based on the description of outcrops, i.e. identifying the different geological rocks in our study area. Rocks are differentiated by their color, texture and mineralogical composition. For this study, a number of tools were indispensable in the field: GPS (Global Positioning System), clinometer compass, magnifying glass, magnetic pen, geological hammer and camera.

For better understanding of the petrographic characteristics of the rocks in the Soubré sector, four (4) thin sections were produced and studied at the Laboratory of Geology, Mineral and Energy Resources (LGRME) of University Félix Houphouët-

Boigny, Côte d'Ivoire (Table 1). This petrographic study was carried out using a transmitted light optical microscope equipped with an image capture device linked to a computer. Microscopic observations were used to determine the mineralogical parageneses and the texture of the rocks.

3.2 Structural Analysis

Structural analysis and macroscopic field petrography were carried out simultaneously. This analysis consisted in identifying structural and geometric elements such as foliation, schistosity, folding, boudinage, shearing and lineation. These structural and geometric elements were then measured (direction, axial plane and fold axis, dip) using a compass. The planes were measured using the Dip/Dipdirection technique. The various measurements obtained were processed with Orient software to identify the main directions.

Table 1. Location in degree decimals (WGS 84 coordinate system) of the samples studied.

Sample	Latitude	Longitude	Lithology
SB4	5,43878	-6,65798	Migmatitic gneiss
SB6	5,43039	-6,56992	Migmatitic gneiss
SB8	5,59292	-6,67096	Migmatitic gneiss
SB9	5,59023	-6,67337	Migmatitic gneiss
SB11	5.57731	-6.68768	Migmatitic gneiss
SB17	5,3787	-6,53327	Metagranite
SB22	5,31023	-6,52361	Garnet-bearing micaschist
SB25	5,21123	-6,54576	Gneiss
SB29	5,24086	-6,59415	Metagranite
SB32	5,78275	-6,63631	Migmatitic gneiss

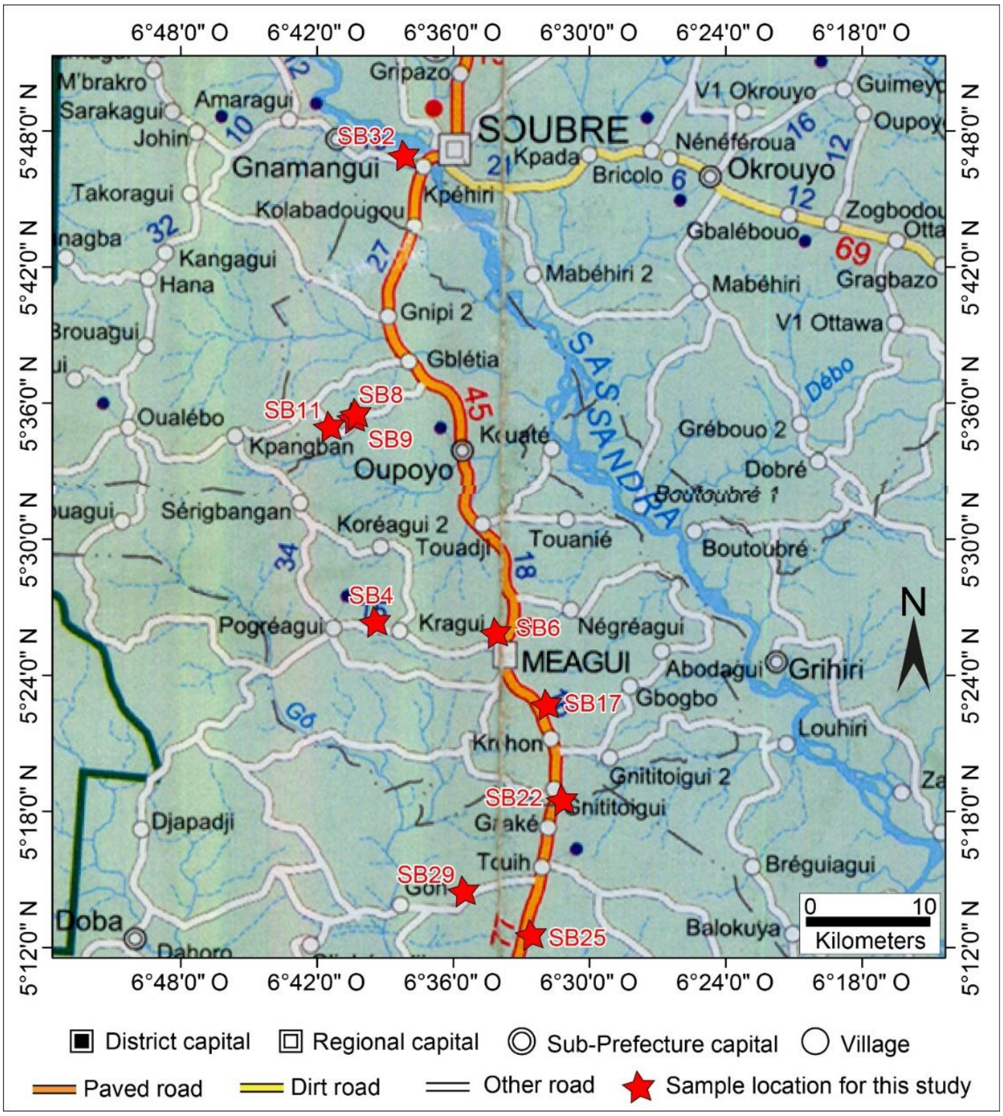


Fig. 2. Location map of the studied samples in red stars (taken from the CESIGsarl 2012 road map).

4 RESULTS

4.1 PETROGRAPHIC CHARACTERISTICS

4.1.1 MIGMATITICS GNEISSES

At outcrop, migmatitic gneisses have a banded appearance with pegmatite intrusions of variable thickness. They are massive lithologies, generally light-gray in color, with a foliated structure. The light-colored parts (leucosomes) have a grainy structure and are composed of quartz and feldspars visible with a magnifying glass. The gray to dark levels are mainly highlighted by biotite flakes and a few rare feldspars and quartz (Fig. 3a and 3c).

Microscopically, migmatitic gneisses have a granoblastic to granolepidoblastic or granonematoblastic texture, with the presence of biotite, feldspar, quartz, amphibole (in some sections), chlorite, muscovite and opaque minerals. Biotite is abundant and elongated, in subeuhedral to euhedral flakes. Feldspars are generally plagioclase, often altered, with occasional microcline grains. Quartz grains in slides show a remarkable rolling extinction with a homogeneous texture, large grains arranged together sometimes forming triple joints often accompanied by polygonization and oriented in foliation while smaller grains are often found in contact with coarser grains. Amphiboles are generally hornblende in longitudinal section, although some secton are basal with two 120° cleavages. Opaque minerals, generally ilmenite and some iron oxides, are xenomorphic and occur within certain minerals such as plagioclase and biotite (Fig. 3b and 3d).

4.1.2 METAGRANITE

The metagranite located not far from the village of Gnititoigui along the road to Méagui is very massive, pink to grayish in slab form and composed macroscopically of quartz, potassium feldspars and biotite with an oriented grainy texture. Grain size is variable (medium to coarse), with some quartz and biotite phenocrysts (Fig. 3e). Microscopically, the mineralogy consists mainly of quartz, feldspars such as plagioclase and microcline, biotite and accessory and opaque minerals. Quartz is highly variable in size and can also be stretched in the foliation, sometimes with triple points. It frequently appears as an inclusion in plagioclase and potassium feldspar. Biotite occurs as long, brown, elongated euhedral flakes, mostly in the foliation or often grouped together. Numerous pleochroic halos within biotites indicate the recurrent presence of radioactive minerals such as zircons. Feldspars sometimes show the beginnings of sericitization. Finally, the opaque minerals are generally ilmenite and magnetite (Fig. 3f).

4.1.3 GARNET-BEARING MICASCHIST

Micaschists outcrop to the south of the study area, but particularly after the town of Méagui on the way from Soubré. They are located between the village of Gnititoigui and Gnaké. This rock was observed in slab and dome form. Macroscopically, garnet micaschist is dark grayish in color, with medium to coarse grains (Fig. 3g). Micaschists are composed of quartz, biotite, muscovite, garnet, plagioclase and accessory opaque minerals. Biotite, rarely grouped in beds, is abundant and gives the rock a schistose structure. Garnet grains can be identified with the naked eye. Under the microscope, we observe a matrix of quartz beds and a few feldspars separated by rods of biotite and sometimes muscovite. Garnets in the form of globular blasts show clear contours with quartz grain inclusions clustered at the core (Fig. 3h).

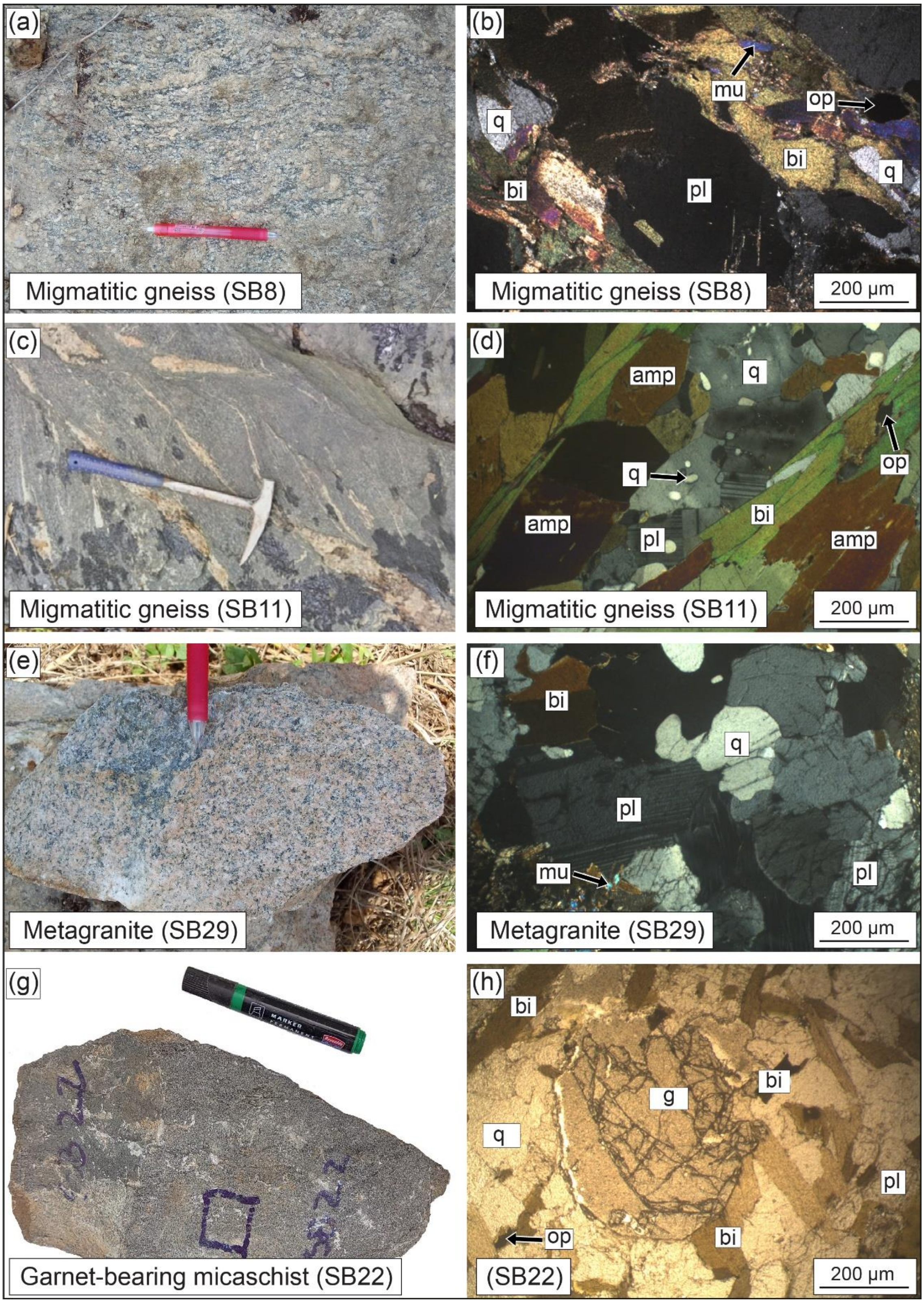


Fig. 3. Photographs (a, c, e and g) and microphotographs (b, d,f and h) showing the studied rocks of the Soubré region. Abbreviations: q = quartz; pl = plagioclase; bi = biotite; g = garnet; mu = muscovite; amp = amphibole, op = opaque mineral.

4.2 Structural Characteristics

4.2.1 Structures observed in migmatitic gneisses

The gneisses observed at the Soubré hydroelectric dam are rich in quartzo-feldspathic minerals with the presence of magnetite and a foliation dipping 60° towards N115 (Fig. 4a). On the outskirts of Soubré on the way to Méagui, a foliation marked by quartzo-feldspathic leucosome levels affects the migmatitic gneisses and is dipping 70° towards N330 parallel to the pegamtite veins. Folds with axial planes parallel to the foliation are sometimes observed, as are ptymatitic folds. These migmatitic gneisses are affected by N166 shears with a sinistral component (Fig. 4b).

At the Gnipi 2 quarry, migmatitic gneisses marked by alternating light and dark bands show enclaves of mafic rocks and pegmatite veins with the presence of a foliation dipping 60° towards N240, intersected by a second foliation dipping 80° towards N310. The appearance of the second foliation leads to the formation of open folds characterized by the folding of the leucosomes dipping 60° towards N240 foliation. The open folds have axial planes parallel dipping 80° to N310 direction. The enclaves of mafic rocks are sometimes asymmetrical with a N150° direction (Fig. 4c).

At Kragui, the migmatitic gneisses also show a foliation dipping 85° to N030, intersected by a second foliation dipping 85° to N110, with the presence of quartz veins parallel dipping 85° to N110 foliation. At Proréagui, migmatitic gneisses characterized by biotite beds and quartzo-feldspathic minerals, some of which are pink in color (orthose), show a 50° to 200° foliation. Shear planes with a sinistral component, in which pegmatite veins are emplaced, strike N080 (Fig. 4d).

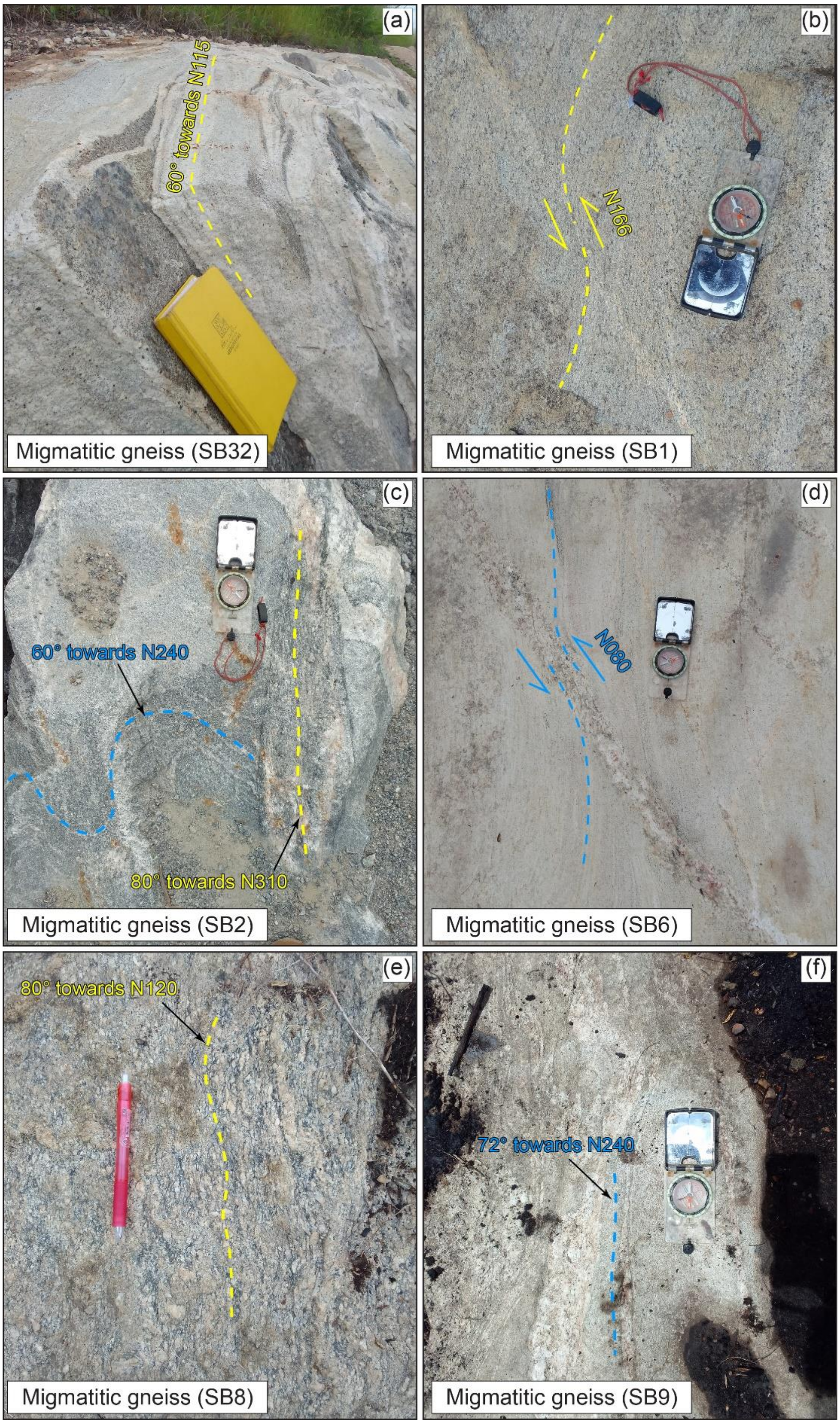
Differents migmatitic gneisses have been observed on the road to Kpangban. Some migmatitic gneisses show feldspar crystals of variable size with a foliation dipping 80° towards N120 (Fig. 4e), while others show a well-marked foliation dipping 72° towards N240 (Fig. 4f) with the presence of intra-foliar folds. The gneisses observed in a stream bed are mylonitic in appearance and show a shear corridor with a sinistral component dipping 60° towards N160. Boudinized and sheared pegmatite veins are observed in this shear corridor (Fig 4g). The gneisses on the road to the village of Gnity Cailloux show dipping 60° towards N160 foliation of folded quartz veins (Fig. 4h).

4.2.2 Structures observed in metagranite

Heading towards the village of Krohon on the Méagui-San Pédro axis, a metagranite with large feldspar crystals was observed with a N120 magmatic foliation. This metagranite is intruded by a pegmatite vein generally parallel to the magmatic foliation. On the road to the village of Goh, the metagranite is less rich in biotite, with a foliation dipping 84° towards N200 (Fig. 4i and 4j).

4.2.3 Structures observed in garnet-bearing micaschist

Just outside the village of Gnititoigui, we observe a garnet-bearing micaschist with occasional sheared quartz veins. In this micaschist, the schistosity dipping 44° towards N230 is taken up by a second schistosity oriented N050, creating a crenulation (Fig. 4k).


(a)
60° towards N115
Migmatitic gneiss (SB32)
(b)
N166
Migmatitic gneiss (SB1)
(c)
60° towards N240
80° towards N310
Migmatitic gneiss (SB2)
(d)
N080
Migmatitic gneiss (SB6)
(e)
80° towards N120
Migmatitic gneiss (SB8)
(f)
72° towards N240
Migmatitic gneiss (SB9)

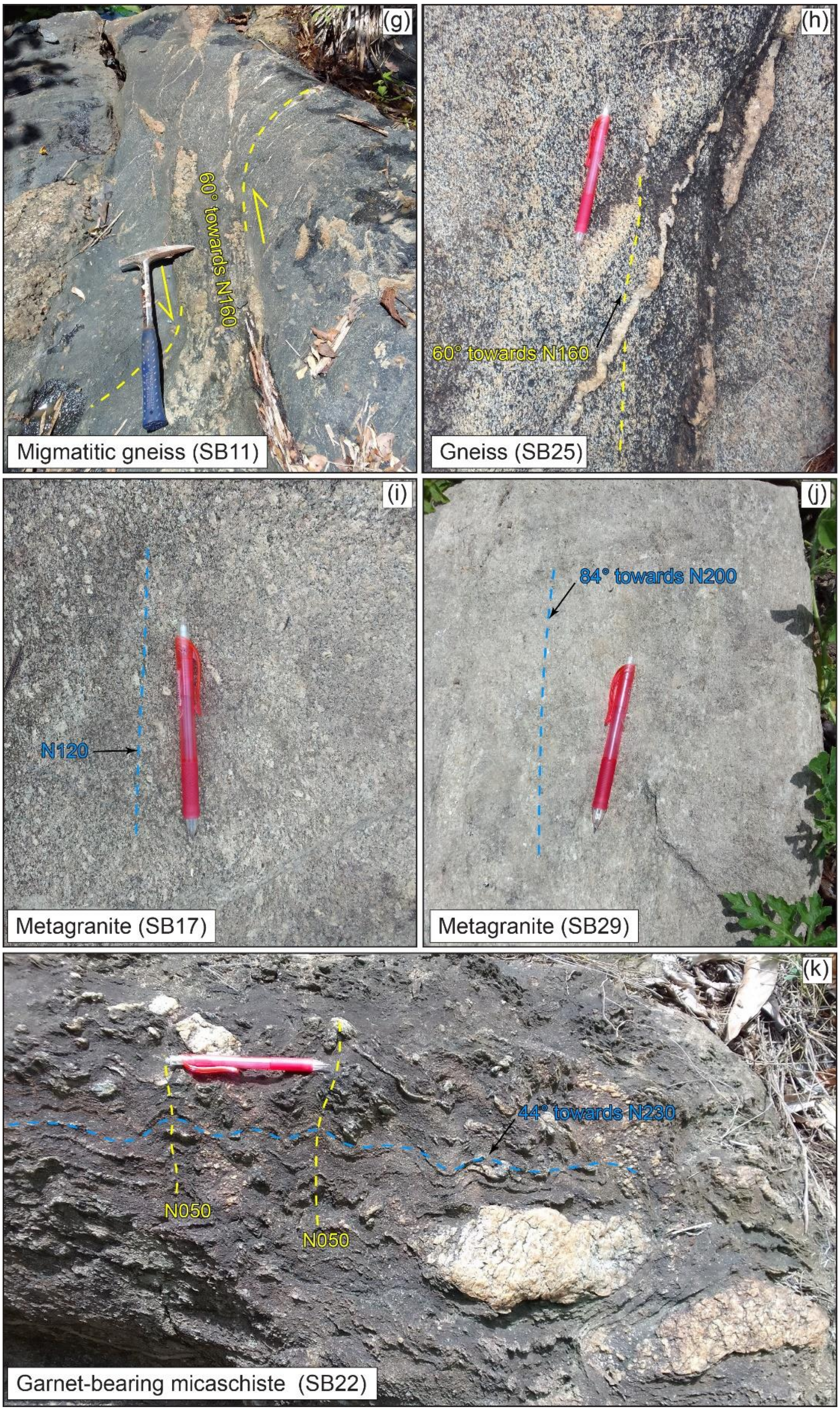


Fig. 4. Field photographs illustrating typical structural relationships (S1, S2) in this study. (a), (e) and (h) S2 in migmatitic gneiss (SB32 and SB8 respectively) and gneiss (SB25). (b), (d) and (g) Sinistral ductile shear zones in migmatitic gneiss (SB1, SB6 and SB11 respectively). (c) and (k) S1 and S2 in migmatitic gneiss (SB2) and garnet-bearing micaschist (SB22). (f) S1 in migmatitic gneiss (SB9). (i) and (j) S1 in metagranite (SB17) and (SB29).

5 DISCUSSION

The rocks studied in the Soubré area consist mainly of migmatitic gneiss, metagranite and garnet micaschist. Migmatitic gneisses with a banded appearance generally contain quartz, feldspar, biotite, chlorite, muscovite and opaque minerals, with occasional amphibole rods. The gneisses studied in this same Soubré and San Pedro area show a tonalitic composition with membership of a trondhjemitic lineage similar to that of the Archean TTGs [2,3]. Also, the grey migmatitic gneisses of San Pedro comprise quartz (40%), plagioclase (35%), greenish biotite (20%) and garnet (3%) [4,9]. The migmatitic character of gneisses in the SASCA domain has also been demonstrated for the Tabou, Monogaga and Balmer gneisses [3,4,10]. The mineralogical composition of the metagranite studied at Soubré is essentially quartz, feldspars such as plagioclase and microcline, biotite, accessory and opaque minerals. This mineralogical composition in the Soubré metagranite is identical to that of the Issia leucogranite, which is quartzofeldspathic with a predominance of microcline, muscovite and biotite [2]. The potassic granite intruding the migmatitic gray San Pedro gneiss is composed of quartz (35%), plagioclase (25%), K-feldspar (25%), biotite (10%) and muscovite (5%) [4]. The Okrouyo alkaline granite studied by Kouassi (2020) [43] has a mineralogical composition similar to that of the Soubré metagranite, being composed of quartz, plagioclase, microcline, biotite and sericite. The garnet-bearing micaschists of Soubré are composed of quartz, biotite, muscovite, garnet and plagioclase with accessory and opaque minerals. Work by Kouamelan et al (1997) [2] in the SASCA area shows garnet and staurotide aluminous micaschists alternating with garnet micaceous quartzites. In the Kounoukou area, the micaschists studied are composed of quartz, biotite, plagioclase, garnet, staurotide, ilmenite and tourmaline [4,9], while at Madié, the micaschists are composed of quartz, plagioclase, biotite, garnet, sillimanite, cordierite and rare staurotides, with accessory minerals such as tourmaline, ilmenite, zircon and monazite [9]. In the town of San Pedro, the micaschist studied consists of quartz, biotite, plagioclase, staurotide, andalusite, muscovite, chlorite and rare sillimanite [9]. According to Papon (1973) [6] a paragenesis composed of biotite-grenate-cordierite-sillimanite shows sufficient intensity of metamorphism to allow anatexis. Thus, the migmatitic gray gneiss of San Pedro records a granulite-facies metamorphic peak with a temperature slightly below ∼8-9 kbar, 650-700°C, while the garnet-staurotide micaschist of Kounoukou shows a prograde evolution with a metamorphic peak at ∼6.6 kbar, 620°C [9]. The P-T evolution of the Madié garnet-sillimanite-cordierite micaschist is dominated by decompression from ∼620-650°C, 7-8 kbar to 620-690°C, 5-6 kbar [9] and San Pedro staurotide micaschist equilibrated at ∼570°C, ∼4 kbar [9].

Structurally, two types of foliation have been observed in the rocks studied in the Soubré area. The first foliation (S1) trends NW-SE, dipping between 40° and 85° towards SW. This first foliation is taken up by a second foliation (S2) trending NE-SW with dips of 60-85°, sometimes to the NW, sometimes to the SE (Fig. 5a and 5b). The deformation stress that generates the S1 foliation is thought to be responsible for setting up the N080 oriented shear with a sinistral component, as well as the folds whose axial planes are parallel to S1. The N166 shear with a sinistral component and the S2 foliation are the result of the same deformation stress, with the presence of folds whose axial planes are parallel to S2 (Fig. 5c and 5d). The work of Koffi et al. (2023) [9] from Grand-Béréby to Sassandra mentions a first NW-SE-trending subvertically dipping S1 foliation with isoclinal folds as well as a second NNE-SSW-trending subvertically dipping metamorphic S2 foliation with tight to open folds and senestial ductile shear zones. In the Gbowé to Grand-Béréby area, phase D1 is a NE-SW subvertical flattening marked by foliation N140˚ and the second phase D2 is progressive ductile deformation [10]. According to, Bard and Lemoine (1976) [44], phase D1 would be characterized by the following structural elements: very tight isoclinal folds, a planar structure intersected by foliated pegmatites and a primary foliation that corresponds to a very strong tectonic transposition of S_n following a S_{n+1} schistosity.

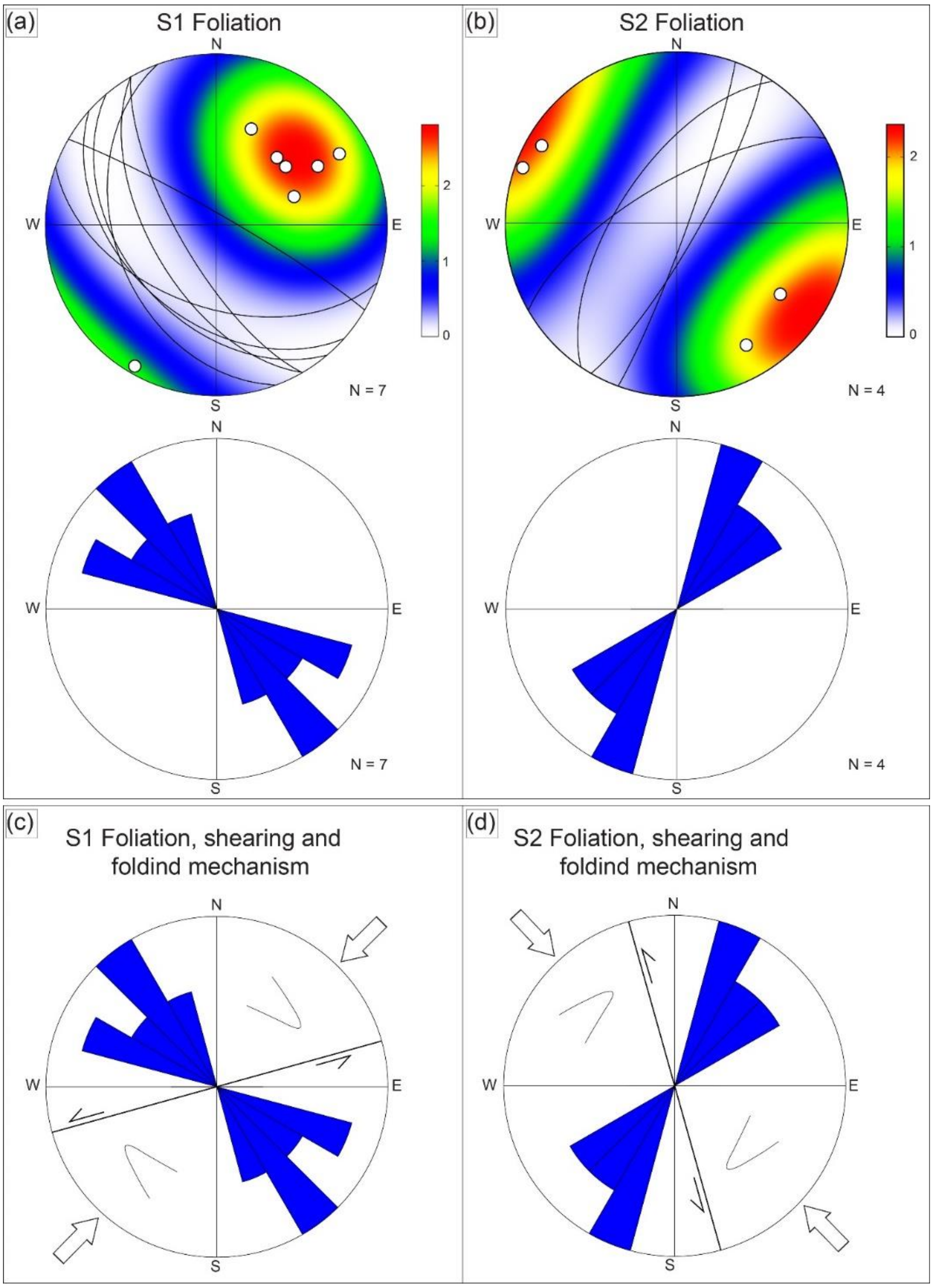


Fig. 5. Equal-area stereoplots of the lower hemisphere, showing S1 (a) and S2 (b) planar foliations and characteristic S1 (c) and S2 (d) stresses.

6 CONCLUSION

The rocks studied in the Soubré region from field and laboratory work are mainly migmatitic gneisses, metagranites and garnet micaschists, all intersected by pegmatites and dolerites. Migmatitic gneisses are generally banded and contain quartz, feldspar, biotite, chlorite, muscovite and opaque minerals, with occasional amphibole rods. The very massive pink to grayish metagranites consist mainly of quartz, feldspars such as plagioclase and microcline, biotite, accessory and opaque minerals. Garnet micaschists are dark grayish in color, medium to coarse-grained and composed of quartz, biotite, muscovite, garnet, plagioclase with accessory and opaque minerals. Two types of foliation have been observed in the rocks studied in the Soubré area. The first foliation (S1) trends NW-SE, dipping between 40° and 85° to the SW. This first foliation is taken up by a second foliation (S2) trending NE-SW with dips of 60-85°, sometimes to the NW, sometimes to the SE. The deformation stress that generates the S1 foliation is thought to be responsible for setting up the N080 oriented shear with a sinistral component, as well as the folds whose axial planes are parallel to S1. The N166 shear with a sinistral component and the S2 foliation are the result of the same deformation stress, with the presence of folds whose axial planes are parallel to S2. All these structural observations in the Soubré sector would be compatible with the structures observed in the SASCA domain on the coast from Grand-Béréby to Tabou.

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