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Full Length Research Paper

Polyphase deformation and evidence for transpressive tectonics in the Kimbi area, Northwestern Cameroon Pan-African fold belt

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The structures of the Pan-African fold belt in North-western Cameroon (Kimbi area) are the result of a succession of several events. Petrographic description and detailed kinematical analysis of the various structures with emphasis on superposed folds discovered in the metamorphic and plutonic complex of Kimbi area provided detailed information on the structures and the relative timing of deformation, which are as follows: (1) an early Pan-African stage (D_1) of tangential movement immediately followed by (2) two stages (D_2 and D_3). D_2 phase is heterogeneous simple shear in dextral transpressive context. D_3 tectonic phase, also marked by dextral transpressional movements, is the phase of superposed folding with a NNE-SSW kinematics direction. D_2 and D_3 are associated with medium-grade amphibolites facies metamorphism. (3) A brittle stage (D_4) responsible for the emplacement of granitic veins, faults and joints. The similarities of these last phases with the central Cameroon shear-zone suggest that the D_3 and D_4 stage are controlled by transcurrents tectonics. Transpressive tectonic seem to be the main deformation style in major shear zones of Central Africa and NE Brazil.

Key words: Transpressive tectonic, Pan-African, tangential movement, transcurrent tectonics, Cameroon.

INTRODUCTION

In a geological reconstruction of NE Brazil and west-central Africa at the end of the Neoproterozoic, the Central Cameroon Shear Zone (CCSZ) appears as the prolongation of the major Brasiliano shear zones of the Borborema Province of NE Brazil (Figure 1), either the Patos shear zone or the Pernambuco shear zone (Caby et al., 1991; Vauchez et al., 1995; Brito Neves et al., 2002; Cordani et al., 2003). The CCSZ is a major lineament of the Pan-African Orogen of Central Africa. The general tectonic significance of Pan-African structures at a regional scale is still in debate. Ngako et al. (2003) describe in central Cameroon a transpressive tectonics during the Pan-African orogeny, resulting in a system of "décrochement-nappe" along the N70°E trending shear zone of the CCSZ with an early sinistral sense of motion (D_2) that was later followed by a dextral sense of shear (D_3). By contrast, Kankeu (2008) and Kankeu et al. (2008; 2009) in Eastern Cameroon suggested an early convergence and compression (D_1), a further compression with crustal compression and peak metamorphism (D_2) and a late Pan-African transpression (D_3).

Information on the tectonic evolution of the northwestern part of Cameroon is still limited. The Precambrian rocks in the northwestern part of Cameroon are poorly known. The few data available were compiled by the Geological Survey of Cameroon (Peronne, 1969) at the scale of 1/500 000. During the last ten years, geochronological investigations have been carried out on some major magmatic complexes: Nkambé granitic complex (Tetsopgang et al., 1999; Tetsopgang et al., 2008), Ngondo granitic complex (Tagne Kamga et al., 1999; 2003), Bandja charnockitic massif (Nguiessi et al., 1997), Tibati plutonic complex (Nzenti et al., 2006),

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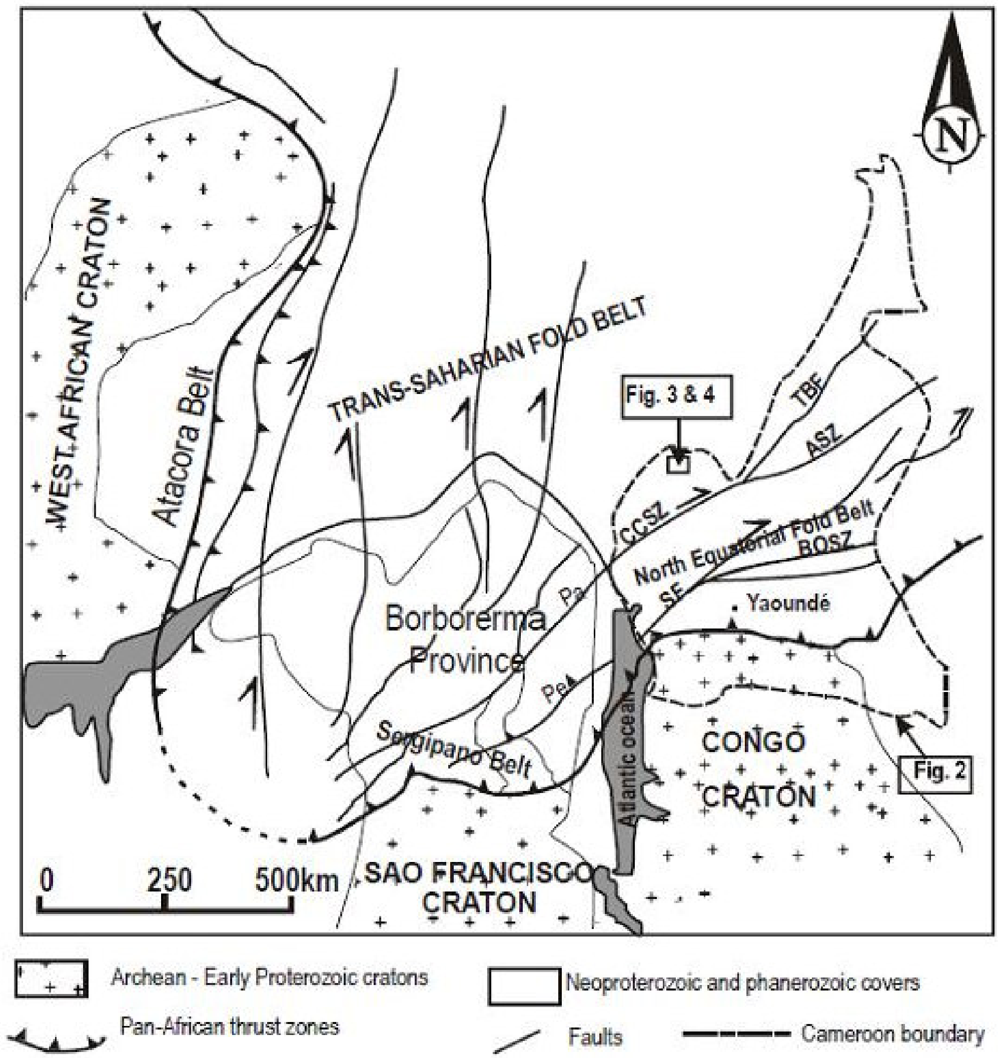


Figure 1. Pre-drift reconstruction of Pan-African and Brasiliano terranes (modified from Castaing et al., 1994): CCSZ: Central Cameroon Shear Zone; ASZ: Adamaoua shear zone; BOSZ: Betaré-Oya Shear Zone; SF: Sanaga Fault; TBF: Tibati Banyo Fault; Pa: Patos fault; Pe: Pernambuco shear zone.

Bantoum granitic complex (Nzolang et al., 2003), and Tonga granitic complex (Tanko Njiosseu et al., 2005) in the central domain. It is suggested that the emplacement ages of these complexes span from the early stages of the deformation (the development of orthogneisses) to the late uplift stages (post-tectonic massifs) of the Pan-African fold belt in Cameroon (Nzenti et al., 1988; Penaye et al., 1989; Nguiessi et al., 1997; Toteu et al., 2001; Tanko Njiosseu et al., 2005). There is a need of field data providing detailed information on the structures and the timing of deformation. Toward this aim we study the plutonic complex of Kimbi area and its metamorphic rocks. The Kimbi plutonic complex is an elongated unit with its long axis sub-parallel to the direction of the Central Cameroon Shear Zone (CCSZ: Ngako et al., 1991) in the west central part of the Pan-African North-Equatorial Fold Belt (PANEFB; Nzenti, 1998; Nzenti et al., 1988).

The data presented in this paper intend to provide: (1) a petrographic description and detailed kinematical analysis of the various structures with emphasis on folds discovered in this area, (2) the various deformation phases from micro-scale to macro-scale and (3) the deformation regime of each tectonic phase.

GEOLOGICAL SETTING AND PREVIOUS WORK

The North-Equatorial Fold Belt or Central African Orogen is a major Pan-African Orogen linked to the Trans-Saharan Belt of western Africa and to the Brasiliano Orogen of north eastern Brazil. In Cameroon, the Pan-African realm (Nzenti et al., 1994; Nzenti, 1998; Ngnotué et al., 2000) is made of three domains from South to

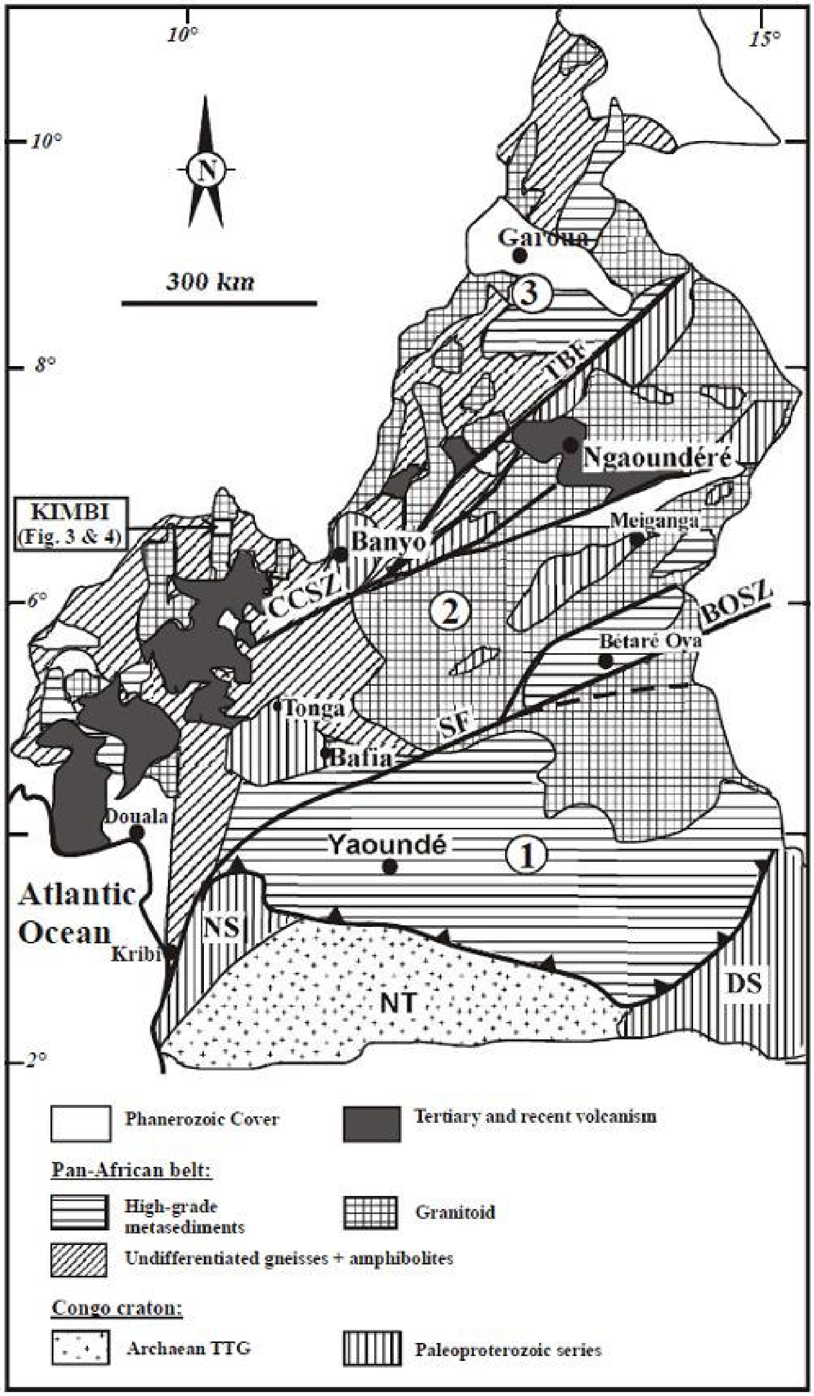


Figure 2. Geologic map of Cameroon (modify from Ngnotué et al., 2000) showing location of the Kimbi area and major lithotectonic domains. CCSZ: Central Cameroon Shear Zone; BOSZ: Betaré-Oya Shear Zone; SF: Sanaga Fault; TBF: Tibati-Banyo Fault; NT: Ntem complex; DS: Dja Series; NS: Nyong Series. (1) Southern Domain; (2) Central Domain and (3) Northern Domain.

North (Figure 2):

(1) The southern domain comprises Pan-African metasedimentary units such as the Ntui-Betamba, Yaoundé and Mbalmayo units. The protoliths of these units were deposited in a passive margin environment at the northern edge of the Congo Craton and were metamorphosed under high P- high T (10-12 Kb, 800°C;

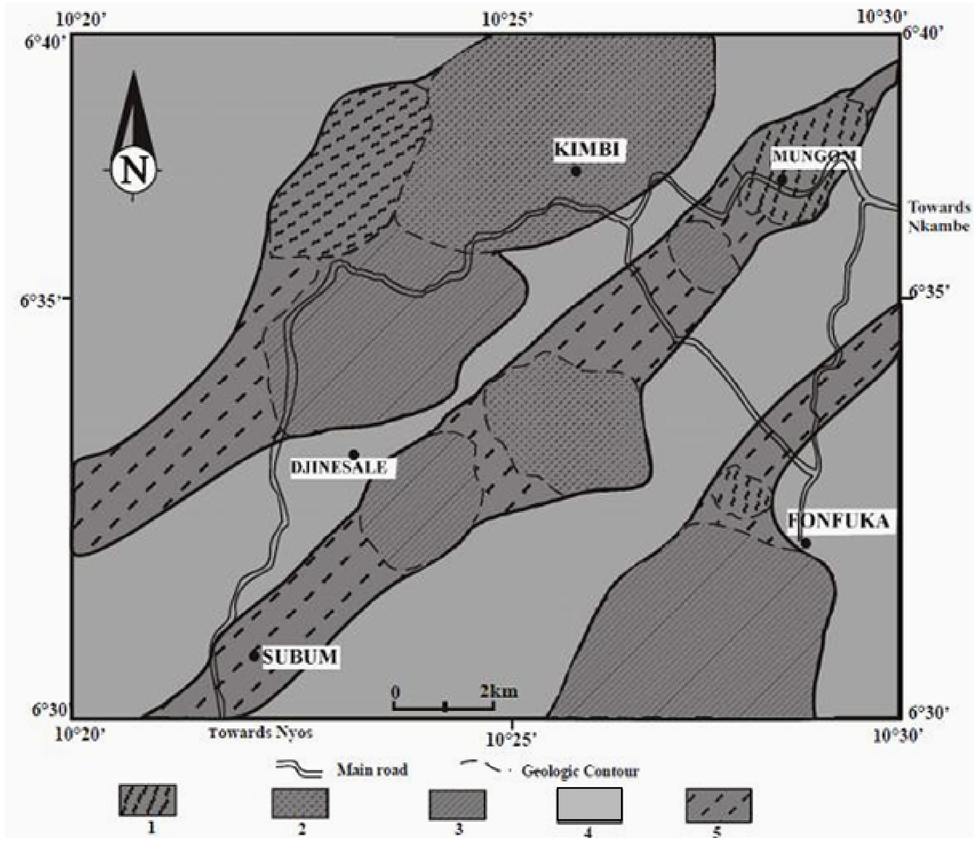


Figure 3. Geologic map of the study area. (1) Gneiss, (2) Amphibolite, (3) Orthogneiss, (4) Granitoïd, (5) Mylonite.

Nzenti et al., 1988) conditions at 616 Ma (Nzenti et al., 1988; Penaye et al., 1993; Ngnotué et al., 2000). An alkaline magmatism (Nzenti, 1998) was also recognized in association with these Pan-African units. The rocks of this southern domain were thrust onto the Archaean Congo Craton towards the South (Nédélec et al., 1986; Nzenti et al., 1984, 1988). Recent studies (Mvondo et al., 2007) showed that this domain were affected by four stages of ductile deformation, corresponding to alternating phases of E-W to NW-SE contraction (D_1, D_3) and N-S to NE-SW extension (D_2). The D_1 phase is responsible for the nappe stacking. The thrust continues towards the East, forming the Oubanguides Nappe in the Central African Republic (Rolin, 1992).

(2) The central domain lies between the Sanaga fault to the south and the Tibati-Banyo fault to the North. These large NE-striking transcurrent faults, as well as the Adamaoua fault inside the central domain, are regarded as possible prolongations of the major shear zones of NE Brazil in a pre-drift Gondwana reconstruction (Castaing et al., 1994). This central domain consists of Archaean to Palaeoproterozoic high-grade gneisses intruded by widespread Pan-African syntectonic plutonic rocks of high-K calc-alkaline affinities (Nguiessi et al., 1997; Tagne Kamga et al., 1999; Tagne Kamga, 2003; Tanko Njiosseu et al., 2005; Njanko et al., 2006; Nzenti et al., 2006; Ganwa et al., 2008).

(3) The northern domain consists of subordinate 830 Ma-old metavolcanic rocks of tholeiitic and alkaline affinities associated with metasediments known as the Poli series. Widespread 630 - 660 Ma-old calc-alkaline plutonic rocks, presently orthogneisses, result from a major episode of crustal accretion. A Palaeoproterozoic crustal source in this region is attested by the presence of 2 Ga old inherited zircons in the plutonic rocks (Toteu et al., 1987).

The study area at Kimbi (Figures 3 and 4) extends over 200 km^2 and belongs to the western part of the central domain. Previous geological investigations (Peronne, 1969) only recognized migmatitic gneisses and granites. Actually, the area is formed of two distinct lithotectonic sets (Figure 3): a metamorphic assemblage and a magmatic unit. The metamorphic assemblage is composed of banded amphibolites, fine-grained amphibolites and gneisses. The magmatic set comprises biotite-granites, hornblende-biotite-granites and orthogneisses intruded by aplitic veins. The plutonic rocks intruded metamorphic rocks units during the Neoproterozoic orogenesis at ≈ 560 Ma (Chemical Th- U_{total}-Pb Isochron Method dating,

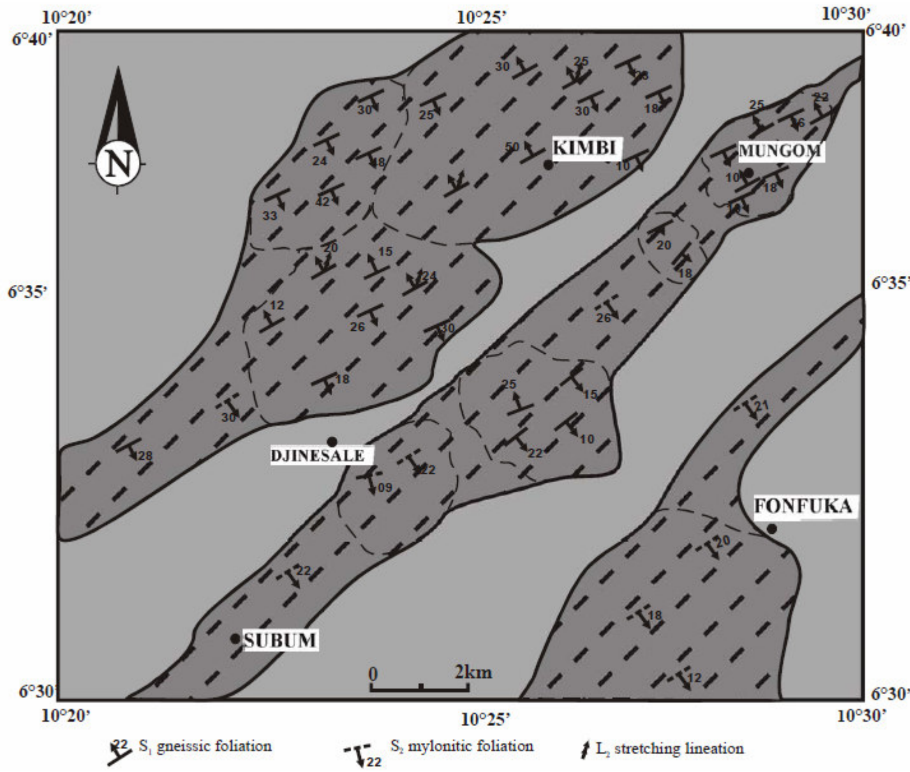


Figure 4. Structural map of the study area.

Tetsopgang et al., 2008).

METHODOLOGY

In this study, we use classical field methods. The structural elements of each tectonic event are recognizable at a metric or centimetric scale and their orientation (strike and dip) were measured using compass and clinometer. Geometric analysis consisted of description and definition of groups of structures as proposed by Hobbs et al. (1976). These data were statistical analyzed in the laboratory using StereoNett software. To get an overall orientation of the foliations, schistosity and fractures, the poles of these planes have been plotted and contoured in lower hemisphere Schmidt diagrams using conventional techniques (Ragan, 1973). The deformation history and kinematic analysis of the whole area were deduced from the field study and detailed mapping of foliation and lineation trajectories in addition to observation of meso- to micro scopic criteria of coaxial or non coaxial strain (e.g. symmetry or asymmetry of shear bands, tails around porphyroclasts, folds).

RESULTS

Petrography

The Neoproterozoic rocks of the Kimbi area comprises metamorphic rocks (amphibolites and gneisses) intruded by magmatic rocks (orthogneisses and granite), all of which have been locally mylonitised. The metamorphic rocks outcrops are scarce. They appear as a window in the widespread magmatic rocks.

Amplibolite

The amphibolite is composed of banded amphibolites and fine-grained amphibolites (Figures 5a and c). Banded amphibolites are characterised by 5 cm-thick alternating Hbl and Bt-rich (mineral abbreviation according to Kretz, 1983) and quartzofeldspathic layers. Hbl and Bt-rich layers consist mainly of hornblende, muscovite, epidote, and quartzofeldspathic layers consist of quartz, plagioclase and K-feldspar with subordinate biotite. All these minerals have various sizes and their organisation in the rock point out to the heterogranular granoblastic texture (Figure 5d). The amphibole (green hornblende) crystals (average size = 0.6 mm) are anhedral and presented a sigmoid shape (amphibole fish) with dextral shear movement. Hornblende is commonly replaced by epidote. Most hornblende prophyroblasts contain significant amount of biotite and apatite crystals. The biotite lamellae with 0.8 mm long is showed shape-preferred orientation with the long axis trending parallel to the foliation. Second biotite replacing amphibole is also presents in the rock. Quartz is 0.2 - 0.5 mm across and exhibits polycrystalline ribbons or single crystals with undulose extinction. Fine-grained ovoid inclusions of quartz occur in feldspar. K-feldspar crystals are subhedral, more rarely rounded and contain small inclusions of amphibole and apatite grains.

Fine-grained amphibolites are grey to greenish rocks with granoblastic isogranular microstructure (Figure 5b).

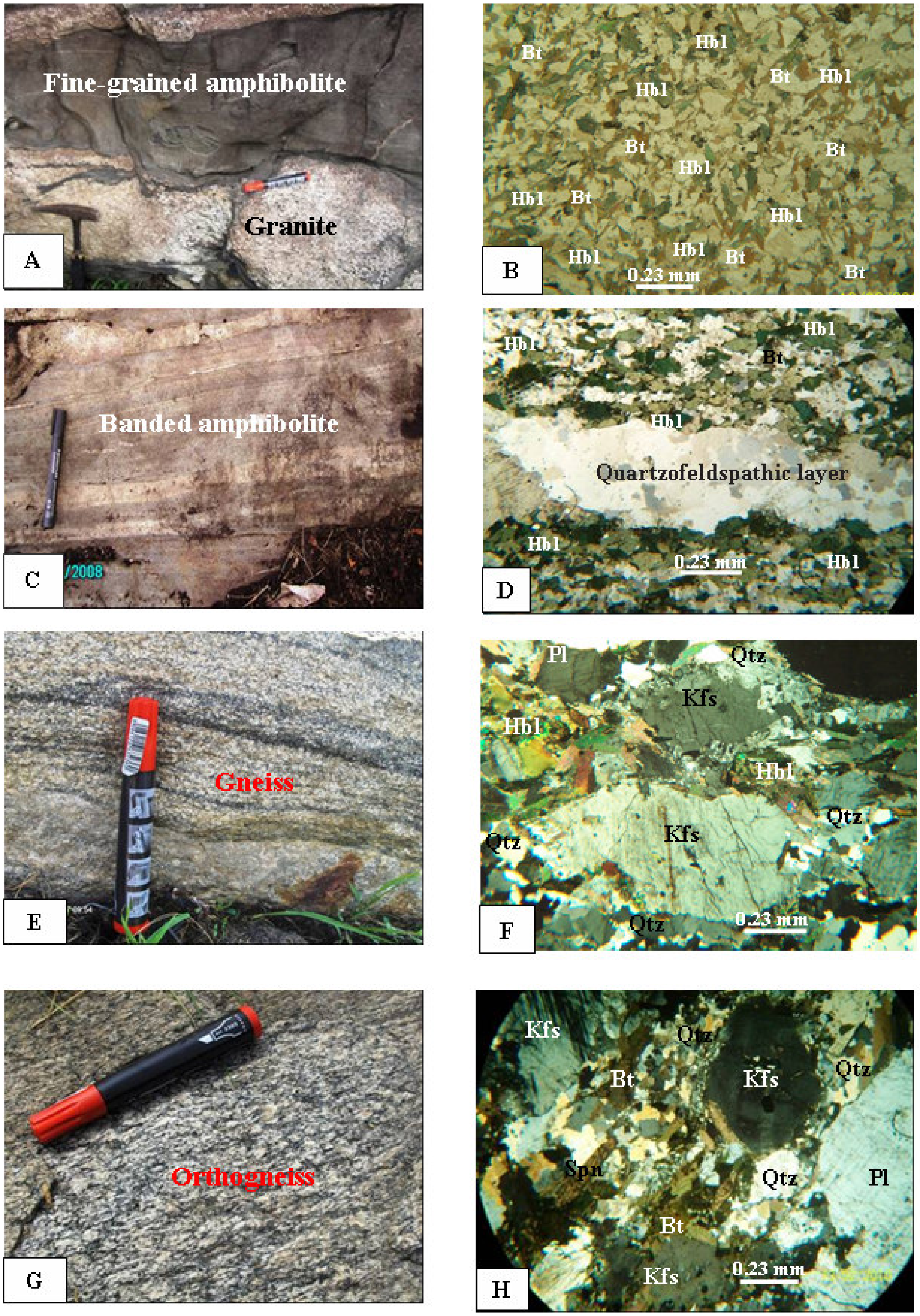


Figure 5. Field occurrence and photomicrographs of main rocks types. A: Fine-grained amphibolite and injected granite. B: Microphotograph of fine-grained amphibolite; C: Field photographs of banded amphibole. D: Microphotogaph of banded amphibolite. E: Photograph of gneiss; F: Microphotograph of gneiss; G: Field photographs of orthogneiss; H: Microphotograph of orthogneiss.

The rocks are rich in ferromagnesian minerals and composed of amphibole (30 - 40 vol.-%), biotite (20 - 35 vol.-%), plagioclase (20 - 30 vol.-%), quartz (12 - 15 vol.-%) and K-feldspar (2 – 5 vol.-%). Accessory phases are zircon, apatite and epidote. The transformation of biotite into chlorite is common and secondary sericite after plagioclase is developed in some samples. Amphibole (green hornblende) anehedral crystals and biotite lamellae are strongly oriented and this orientation defines the foliation on the rock. Zircon and apatite are included in other minerals or are part of the matrix. Epidote grains developed probably due to the hydrothermal alteration of plagioclase and hornblende.

Gneiss

The gneisses are medium- to coarse grained and display distinct mineralogical layering consisting of alternating bands of quartz and feldspar grains of variable sizes and biotite+pyroxene–dominated bands (Figure 5e).The texture of the rock is granoblastic heterogranular (Figure 5f). Mineral associations are polycrystalline ribbon quartz, subhedral K-feldspar and plagioclase, biotite flakes, amphibole fish and pyroxene porphyroblasts. Accessory minerals are apatite, titanite, zircon and opaque. Quartz forms elongated polycrystalline ribbons (0.8 - 1.3 mm in the length) or elongated granoblastic aggregates. K-feldspar exhibits sigmoidal (0.2 x 0.5 mm) or almond shape (1 x 1.5 mm), and presents perthitic exsolutions of albite. Development of myrmekites at the grain boundaries is also observed. Most K-feldspar crystals contain small inclusions of titanite, apatite, biotite flakes or quartz grains. Some crystals have microfractures filled by quartz. Plagioclase occurs as partly elongated, subhedral or rounded crystals that may be aligned sub parallel to the foliation and may show undulatory extinction or deformational twinning. All plagioclase and some K-feldspar crystals are rimmed by quartz aggregates. Biotite occurs as flakes of various dimensions that may be clustered, most of which derive from destabilization of amphibole or pyroxene. Amphibole is a green hornblende with almond shape and contains small euhedral inclusions of apatite, zircon and opaque. Asymmetrical and symmetrical K- feldspar porphyroblasts in the gneisses define a strong mineral lineation parallel to the alignment of mica flakes and amphibole fish in the gneisses and the amphibolites, respectively (Figure 5f).

Orthogneiss

Orthogneisses are the main lithologic unit of the magmatic rocks. They crop in the whole area, precisely in Fonfuka, Mungom, Kimbi and Subum (Figure 4), as large bodies roughly elongated following the NE-SW direction. The rock is coarse-grained (Figure 5g) and the main constituent minerals are k-feldspar (up to 50 Vol. %), quartz (20 - 25 Vol.%), plagioclase (10 - 15 Vol.%), biotite (5 - 8 Vol.%) and muscovite (3 Vol.%) (Figure 5h). Accessory minerals include titanite, zircon and apatite. The k-feldspar megacrysts (up to 4 x 2 cm in size) are embedded within a fine grained matrix which is composed of quartz grains. Some of these k-feldspar megacrysts and rare plagioclase phenocrysts are subeuhedral and display numerous microfractures. These microcraks are filled by quartz neograins and mica. Myrmekite is common at the contact between k-feldspar and plagioclase and perthite is also observed. Weakly deformed quartz is present as equidimensional neograins with an average grain size of 0.8 mm. Evidence for intra-crystalline deformation, such as undulouse extinction and kink bands in quartz, kink and deformation twins in plagioclase, two sets of subgrain boundaries, and development of secondary biotite have also been observed.

Granite

The granites are fine to coarse-grained and display inequigranular microstructure (Figure 5a). They are composed of quartz (20 - 25 vol.-%), K-feldspar (15 - 20 vol.-%), plagioclase (25 - 35 vol.-%), biotite (10-20 vol.-%); accessory minerals including titanite (2 - 4 vol.-%), zircon, apatite and ilmenite (≤2 vol.-%). K-feldspar shows perthitic exsolutions of albite. The crystals are subhedral, more rarely rounded and contain small inclusions of biotite flakes, euhedral plagioclase and quartz. Plagioclase crystals display various shapes: they occur as partly elongated, subhedral or rounded and show undulatory extinction. Biotite occurs as flakes of various dimensions that may be clustered or forms euhedral inclusions in feldspars.

Mylonites

The mylonites are derived from precursor rocks and showed progressive increase in the intensity of deformation from the external limits of the shear zones to the centre. The mylonitised rocks have sheared and stretched quartz ribbons with an anastomosing pattern of intervening lenses of less deformed gneiss and schist. The quartz ribbons and a retrograde mineral association comprising hornblende, muscovite, epidote, opaques and biotite define a mineral lineation in the mylonites

Structural pattern

The Kimbi area basement is characterized by a poplyphase deformation: Four tectonic events (D_1-D_4) have been recognized.

D_1 phase of deformation

The D_1 event is only recorded in the metamorphic rocks and it is associated with the development of an S_1 foliation, F_1 isoclinal folds and $ß_1$ boudins.

The S_1 foliation is the major structure in the metamorphic unit. It is outlined by a compositional banding

(Figures 6a and b) and by the preferred orientation of biotite, amphibole and platy quartz. S_1 foliation was progressively transposed by D_2 deformation phase and it is recognizable only as relic at the microscopic scale. A total of 179 measurements of dips and strikes of S_1 surfaces were taking. The foliation surfaces S_1 have low to moderate dips (0 - 45°) mainly to the NW and secondarily to the SE. The poles to S_1 from the main outcrops show a girdle distribution (Figure 7a), which may imply folding around a gently NE plunging axis. The related lineation is conspicuous and corresponds to a mineral and stretching lineation. It trends NE-SW with a gentle plunge (0-10°) mainly towards the NE, but secondary SW plunging lineations are observed.

Clearly visible in the banded amphibolites, the $ß_1$ boudins are developed on the quartzofeldspathic layers (Figure 6a), and can be attributed to multilayer boudins of Ghosh and Sengupta (1999). They have a symmetric shape and their long axes are parallel to the S_1 foliation, suggesting a co-axial deformation.

D_2 phase of deformation

This tectonic phase is well-recorded in both the magmatic and metamorphic rocks units. It is characterised by a heterogeneous deformation affecting the previous D_1 fabric. D_2 deformation is associated with the development of S_2 mylonitic foliation, C_2 ductile shear zones, F_2 folds and L_2 stretching and mineral lineations.

In magmatic rocks, the S_2 mylonitic plane is defined by biotite flakes, K-feldspar sigmoidal crystals, mica fish and platy quartz (Figure 6e). The distribution of S_2 surfaces from the main outcrops around Kimbi area show a girdle distribution. Their planes have moderate to high dips predominantly to the Southeast (Figure 7b). The angle between S_2 and C_2 is often clearly visible and can reach 5°, indicating strong shear values.

In metamorphic rocks, the S_2 planes are unequally distributed. They are mostly visible, in layered amphibolites and gneisses, as axial plane schistosity for the F_2 folds (Figure 6f); at a microscopic scale, S_2 is marked by biotite flakes and hornblende needles. $ß_2$ asymmetric boudins are developed in the banded amphibolite. According to Ghosh and Ramberg (1976); Hanmer (1986) and Goldstein (1988) these types of boudin are typical for shear zones. The asymmetric aspect show that they are pre- to syn-shearing (Goldstein, 1988) boudins, with the initial layers trending oblique to the shear zone.

C_2 shear zones appear as steep ductile zones which sheared the S_1 foliation. Their dip is not less than 50° (average orientation N130°E, 60SW) and is nearly constant in the study area. In some places, the spacing of the shear zones varies from 10 - 25 cm for the tighter ones to some metres or more. Locally, it gives the amphibolites or gneisses a strong tectonic banding by transposition of the previous S_1 foliation. The shear planes are distinct by injections of granitic liquids (Figures 6g and h).

The L_2 lineation is conspicuous and nearly perfectly oriented in the whole region. It has a N28°E - N70°E trend, parallel to F_2 fold axes and plunge can reach 40° toward the NE ; it is linked to C_2 shears or lies in the S_2 schistosity and shows all the characters of a mineral and stretching lineation (Figure 6i). In addition of these two types of lineation, the hinge lines of microfolds in a foliated amphibolite define a vertical crenulation lineation (Figure 7j).

D_3 phase of deformation

This phase is typically a phase of superimposed folding. In fact the structures associated to this phase of deformation are the result of the transposition and reorientation of the D_2 structures.

S_3 schistosity overprinted the pre-existing S_2 schistosity. The S_3 planes are equally distributed; they trend N40-50°E with moderate dip (45 - 50°) toward the NW. They are mostly visible as axial plane schistosity for the F_3 folds (Figures 6o and p). At a microscopic scale, S_3 schistosity is marked by elongated shape of quartz crystals, biotite and amphibole flakes.

The L_3 lineation is a stretching lineation formed by platy quartz, amphibole fish and feldspar rods. A L_3 lineation associated with S_3 is sub-parallel to the F_3 fold axes (Figure 8p) with a low to moderate plunge toward the northeast (5 - 30°).

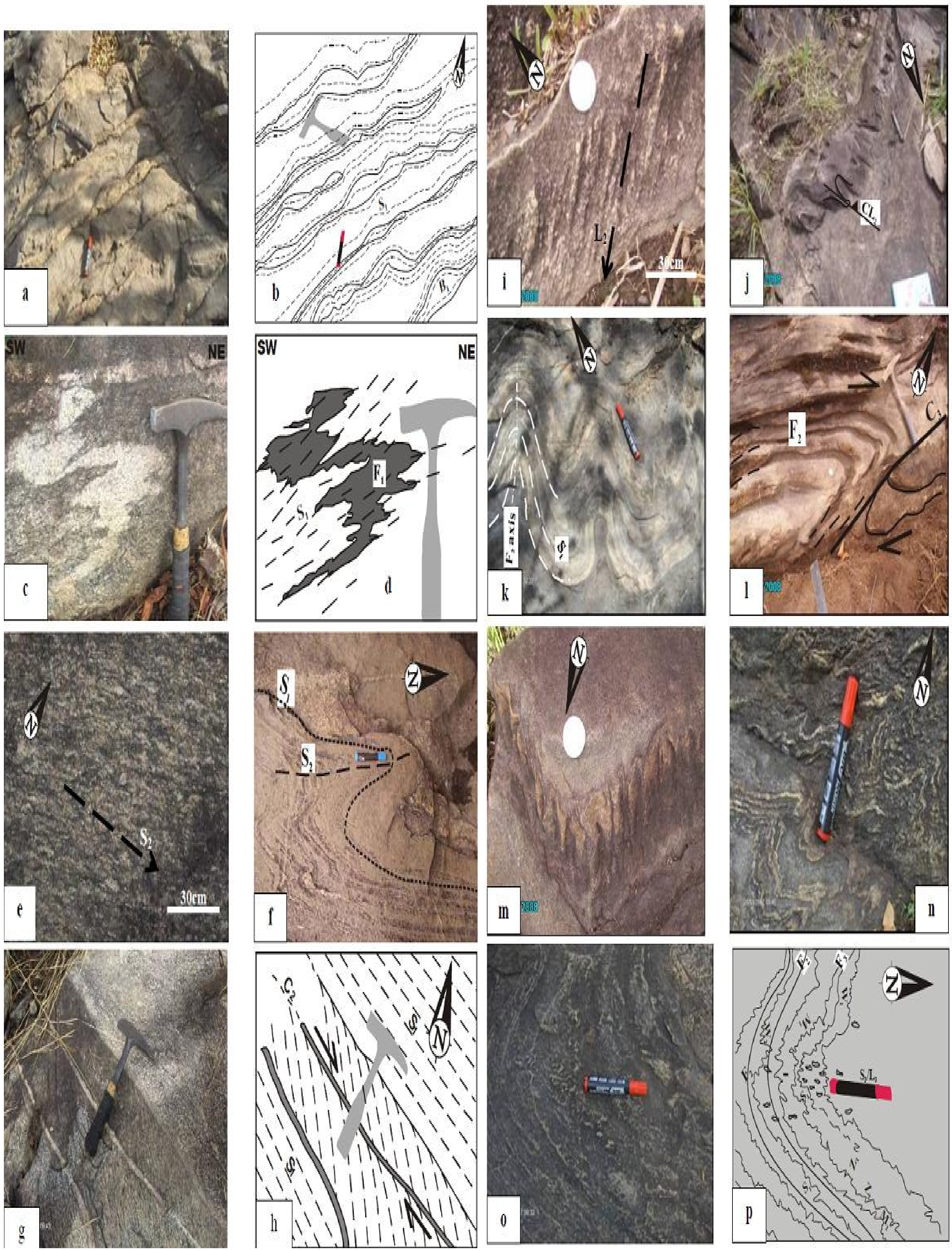
The C_3 shear plane is clearly visible in the « Ndong river » flagstone. The F_2 fold limbs are dissected by the C_3 shear planes (Figures 6s and t). The shearing movement associated with the D_3 phase of deformation is dextral and trend average N 45°E, 30° towards the SE.

D_4 phase of deformation

This phase is marked by three main types of late sub-vertical fractures (Figures 7v and 7w) which are dyke (granitic veins), strike-slip, and micro-faults. The veins are either aplitic or pegmatitic. The D_4 structures show three main orientations (Figure 7k): (i) N30-40°E corresponding to the one of the direction of Cameroon Central shear zone; (ii) N70 - 80°E equivalent to the Adamawa Faults (Moreau et al., 1987; Ngnotué et al., 2000); and, (iii) N140 - 150°E also found in the southern part and the eastern part of the central domain (Tombel basement) of the Pan-African fold belt and interpreted as traces of the Benue trough (Nzenti et al., 1988; Ngnotué et al., 2000; Njome and Suh, 2005).

Folding events

F_1 folds occur only as decimetre-sized isoclinal folds with S_1 parallel to the axial plane schistosity (Figures 6c and d). these structures are not observed in the orthogenesis,


a
b
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30cm
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Figure 6 Cont.

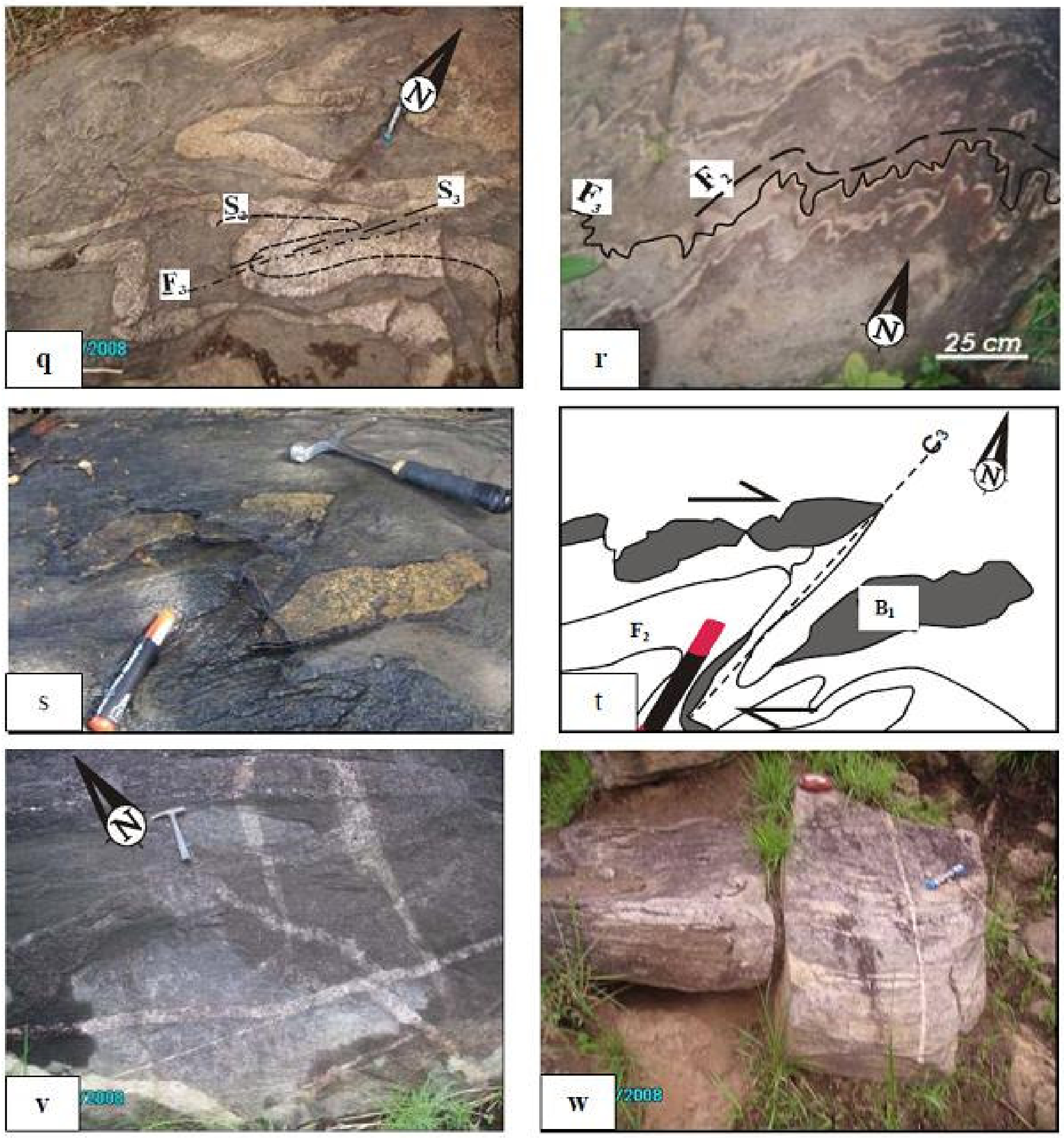

Figure 6. Field views of main structural elements on Kimbi area. (a) and (b): S_1 foliation outlined by a compositional banding. (c) and (d): F_1 isoclinal folds with S_1 schistosity parallel to the axial plane of the fold. (e): S_2 mylonitic schistosity in magmatic unit. (f): S_2 axial plane schistosity for the F_2 folds in metamorphic set. (g) and (h): C_2 shear planes are highlighted by injections of granitic veins (note the dextral sense of movement). (i): L_2 stretching lineation. (j): crenulation lineation, CL_2 (coin is 2cm wide). (k): F_2 Upright folds. (l): F_2 recumbent folds. (m): F_2 accordion folds (coin is 2cm wide). (n) F_2 disharmonic folds. (o) and (p): F_3 minor folds overprinting F_2 large folds (Note the asymmetric shape “S” or “Z” and the symmetric shape “M” or “W” of F_3 folds and S_3 axial plane schistosity for the F_3 folds). (q) and (r): F_2-F_3 fold interference patterns (note the development of F_3 folds on the F_2 folds). (s) and (t): F_2 folds limbs are cut by the C_3 shear planes (note the dextral shearing movement). (v): D_4 fractures.
Nota: The marker on figures a, b, f, j, k, n, o, p, q, s and t is 13.5 cm long while for Figures c, d, g, h, l, hammer is 30 cm.

implying that the gneisses post-date de D_1 phase. F_2 folds overprint the D_1 structures. The S_1 schistosity is folded by the F_2 folds.

The D_2 folds represent the main folding phase. They are clearly visible at megascopic, mesoscopic and micro-scopic scale. At megascopic scale (whole area) F_2 folding displays antiformal and synformal structures with axes oriented NE-SW. The F_2 mesoscopic folds have S_2 as axial plane schistosity. All the axial trends are parallel and vary between N15°E and N70°E with low plunge (10

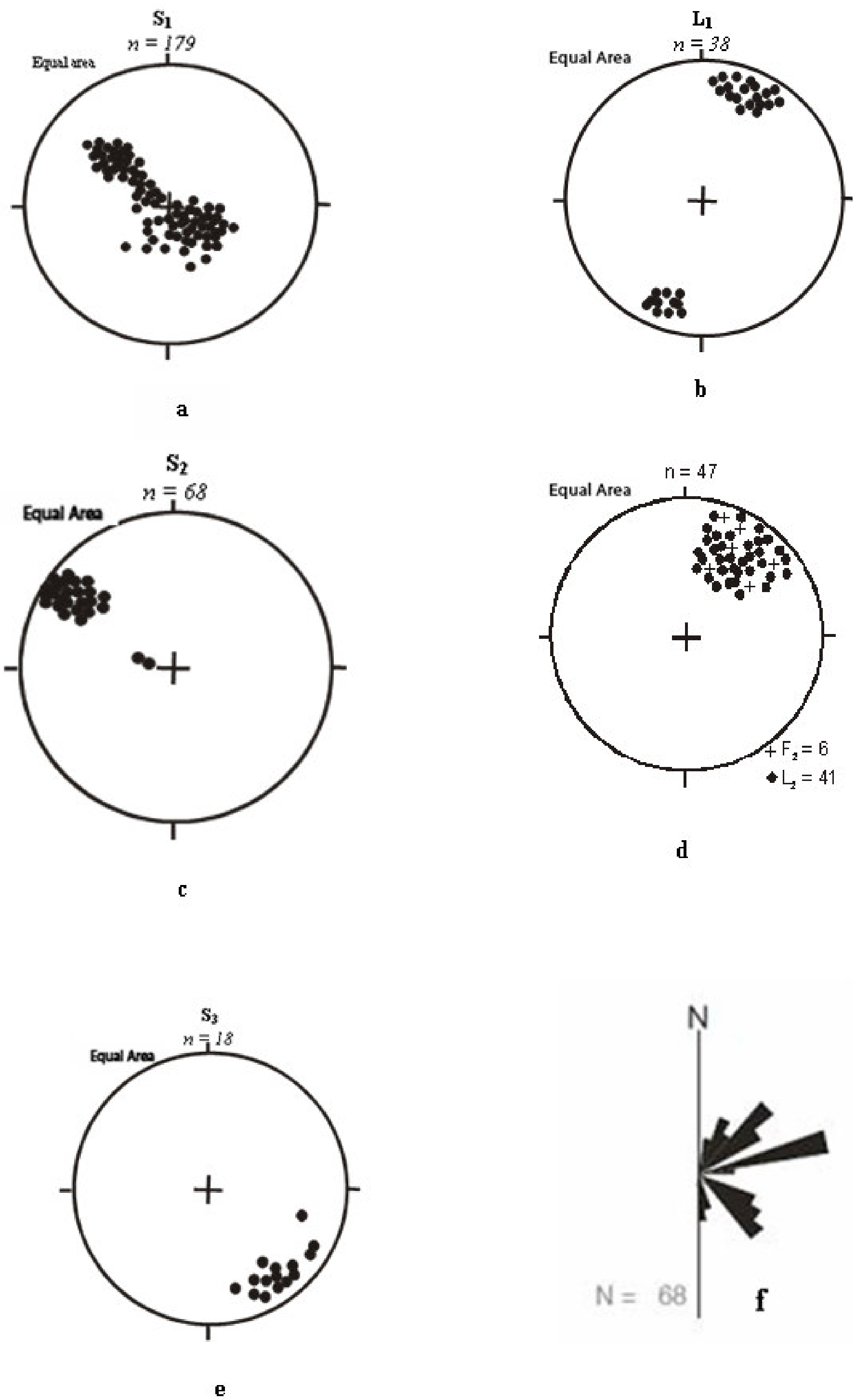

Figure 7. Equal-area Schmidt lower hemisphere projection of structural data: (a): Poles to S_1 foliations; (b) L_1 mineral and stretching lineation; (c) Poles to S_2 foliations; d) L_2 Stretching lineation and F_2 fold axes; e) Poles to S_3 foliation and (f): Rose diagram of fracture planes depicting three main structural trends (N30-N40E, N70-N80E and N140-N150E).

- 30°) toward the NE. The axes of these folds are nearly parallel to the stretching lineation and could be large-scale sheath folds (Coward, 1981). The metamorphic rocks of the Kimbi area are strongly folded by F_2 folds. These F_2 folds have also various morphological aspects (Figures 6k, 6l, 6m and 6n): (i) upright folds; (iii)

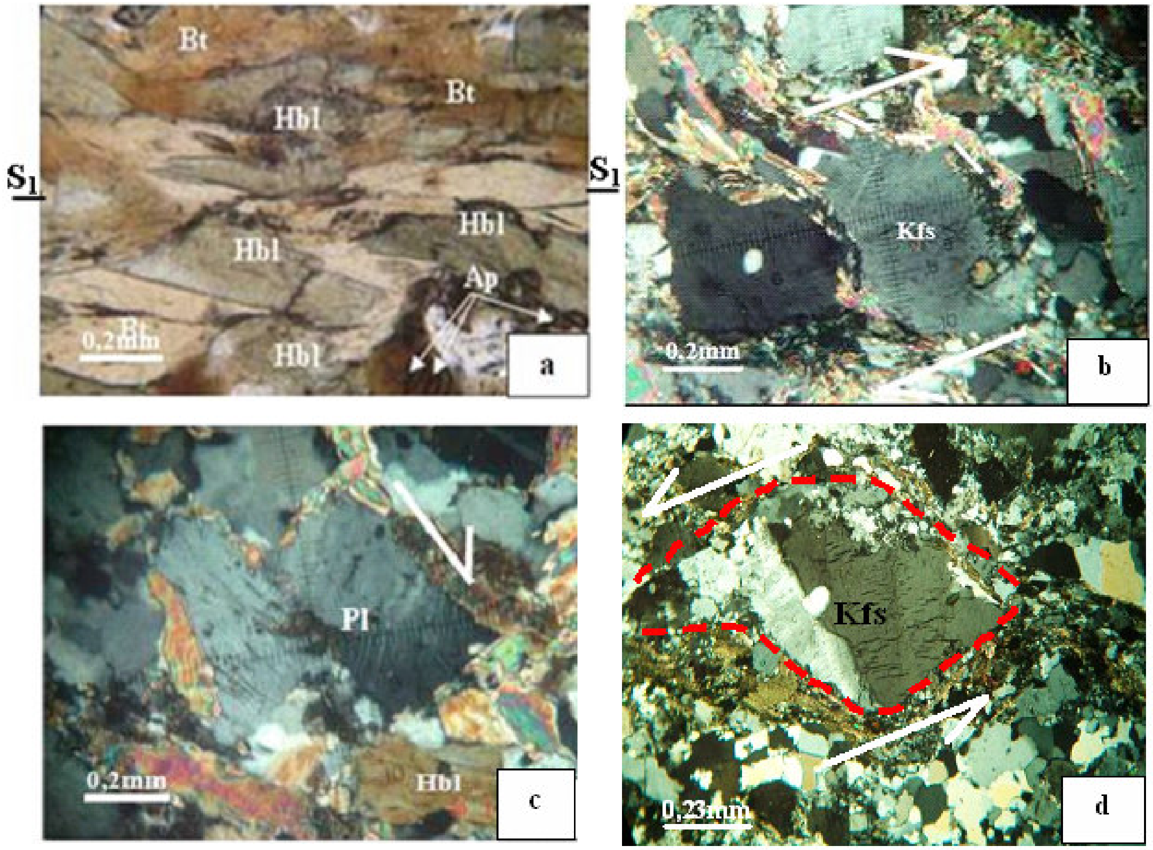

Figure 8. Microstructures of the Kimbi area. a: S_1 schistosity defined by mica flakes and amphibole fish in amphibolite; b: Asymmetrical feldspar prophyroclasts showing dextral shearing; c: Sheared feldspar prophyroclast; d: Asymmetrical feldspar prophyroclasts showing sinistral shearing. (Mineral symbols after Kretz, 1983).

recumbent folds; (iii) accordion folds and (iv) disharmonic folds. The wave length of the many F_2 folds varies from 15 cm to 30 cm with the amplitude of 10 - 20 cm.

The F_3 folds (Figures 6q and r) typically form interference patterns that arise as a result of the development of later minor folds across the earlier structures. The new small-scale folds have either asymmetric S- or Z-shape and symmetric M-or W-shape (Type-3 of Ramsay, 1967, pp. 530 - 538; Ramsay and Huber, 1987, pp. 475 - 504) depending upon their location in the large F_2 folds (Figure 6p). The fold axes of F_3 folds are parallel with F_2 fold axes. Thus, F_3 orientation is approximately coaxial with the earlier recumbent F_2 folds.

Kinematic indicators

Kinematic analysis involved measurements of stretching and mineral lineations, foliation planes and S-C foliations, as well as determination of shear sense based on the interpretation of asymmetric structures. In the Kimbi area, global foliation data show mainly NW and secondary SE dipping. These variations may be attributed to the development of fan-like structures. Amplibole fish (Figures 8a) commonly elongated parallel with the S_1 foliation, undeformed and asymmetric protolith boudins, asymmetrical feldspar prophyroblasts (Figures 8b and c), asymmetrical minor folds, are good shear sense indicators and define a predominantly dextral sense of shear, although locally sinistral displacements may also occur (Figure 8d). In some mylonite rocks, foliation plane adopt S-C geometry with dextral shear sense movement. The dextral sense of movement along the shear plane was also deduced from displacement of quartz veins and amphibole prophyroblasts, some of which show rotational movement. In whole area, many groups of ductile shear zone crosscutting the foliation are observed and show a predominantly dextral shear sense.

DISCUSSION AND TECTONIC INTERPRETATION

D_1 deformation phase in the Kimbi area testifies to a thickening stage characterized by intrafolial isoclinal folds. S_1 foliation is dipping oppositely mainly to the NW and secondarily to the SE. This geometry can be considered either as late folding due to thrusting or as a mega flower structure related to transpressive deformation.

D_1 phase is responsible of the nappe stacking that was emplaced horizontally to form a classical fold-and-thrust belt (Burg et al., 1993). The nappe vergence in Kimbi area, deduce from transport direction, is similar to that observed in southern domain of the North Equatorial Panafrican belt (Nzenti et al., 1988; Mvondo et al., 2007). D_1 fabric has been progressively overprinted by D_2 deformation.

The D_2 tectonic phase is the main tectonic phase in the Kimbi area. It is characterised by a diversity of structural elements: (1) the F_2 folds with different morphology, (2) an axial plane schistosity S_2 associated to (3) mineral and stretching, crenulation L_2 lineations, and (4) C_2 shear zone. During D_2 deformation, northeast-southwest oriented mylonitised granitoid has been intruded in the metamorphic rocks. Three mylonitic zones have been distinguished (Figures 3 and 4). These mylonitic zones trend NE-SW, similar to those described by Kankeu (2008) in the eastern part of the Pan-African Fold Belt in Cameroon. Structural analysis of exposed rocks in this shear zone indicates that the mylonitic foliation is dipping to SE, but the stretching lineation is sub-parallel to the strike of the mylonitic foliation throughout the shear zone. Mineral and stretching lineations are oriented close to fold axis. This parallelism suggests that simple shear caused the folding. Lineation fabric gently plunging mainly towards the NE, and secondary towards SW, are consistent with predominance of directional to gently oblique movements. Planar and linear data relationships are also coherent with oblique displacements. The coexistence of folding and shearing in the Kimbi area can be understood as the effect of deformation as the effect of deformation partitioning at mid-crustal depth (Bell, 1981; Dabo et al., 2008). Cobbold et al. (1991), Jones and Tanner (1997) and Tikoff and de Saint Blanquatt (1997) showed that one of the specific consequences of transpression is the partitioning of strain into domains that are predominantly transcurrent associated with domains that are predominantly compressive. In general, the variation in lineation trends is more or less progressive and shows some similarity to the result models for strain partitioning in inclined or oblique transpressional settings (Dewey et al., 1999; Carosi et al., 2005; Dabo et al. 2008). Thus the Kimbi area is an outstanding example of strain partitioning inside a single and relatively small area. Shear sense indicators such as ductile C_2 shear band, asymmetric mantle porphyroclasts, asymmetric boudins are consistently dextral.

The D_3 tectonic phase is fundamentally a phase of tectonic superposition. It is essentially made of F_3 folds resulting in the refolding of the F_2 folds. The other structures acquired during this phase (S_3 schistosity, L_3 lineation and C_3 shear zone) come from the redistribution or the reorganisation of their equivalent of the D_2 phase, in the sense that some remain parallel and others sub-parallel or oblique. Transpressive character of deformation during this phase is shown both by the coexistence of transcurrent and compressive structure and the parallelism of fold axis and lineation. The dextral shear movement is similar to that of the D_2 tectonic phase and the similarity of the D_2 and D_3 structures testify of a progressive deformation during the activity of a major ductile shear zone (Ghosh and Sudipta, 1987).

D_4 is a phase of brittle tectonic with sub-vertical fractures and regional–scale faults. These fractures show three main directions, all corresponding to the main direction of the shear zones in the Central domain of the Cameroon Pan-African fold belt.

The tectonic evolution in the North-western segment of the fold belt commenced with ductile deformation and terminated with brittle deformation. This is a classical feature of brittle-ductile shear zones (Passchier et al., 1993; Nguiessi et al., 1997; Suh and Dada, 1997; Passchier and Trouw, 1998), although shear zones in which macroscopically brittle deformation predates a ductile event have also been described (Imber et al., 2001 and references therein).

The propose chronology is different from the previous work (Yakeu et al., 2007), with three classical phases of deformation (D_1-D_3) phase proposed in this part of the Pan- African North Equatorial Fold Belt, but it similar to that propose by Mvondo et al. (2007) in the Yaoundé segment of Panafrican belt in Cameroon. Our new results show that the Central Cameroon Shear Zone acts in the Kimbi area as a transpressive ductile shear zone. At the regional scale, Neoproterozoic dextral transpression is well documented in Serido belt (Archanjo and Bouchez, 1991) and Ribeira belt (Dehler et al., 2007; Karniol et al., 2008) in eastern Brazil, and is considered to be the main tectonic regime resulting from continental collision at this time. The same tectonic regime has been proposed for Panafrican Trans-Saharan Belt of eastern Nigeria (Ferré et al., 2002). Overall, transpressive tectonic seem to be the main deformation regime in major shear zones of Central Africa and NE Brazil.

Conclusion

In this paper, the results of our petrographic, structural and kinematic analyses show that the complex geometry of Kimbi area is a result of four stages of deformation: (i) The first stage (D_1), characterised by isoclinals recumbent folds, flat-lying schistosity and near-horizontal, stretching lineation, corresponded to tangential movements; (ii) the second (D_2) which is the main deformation phase due to their diversity of structural elements. The deformation style of the D_2 phase is heterogeneous simple shear in dextral transpressive context; (iii) the D_3 tectonic phase, also marked by dextral transpressional movements, is the phase of superposed folding with a NNE-SSW direction; and (iv) a brittle phase which at the regional scale, is contemporaneous with the central Cameroon shear-zone. These new data suggest that nappes and folding are associated with transcurrent tectonics. We also conclude that the brittle deformation is younger than the foliations and the region experienced a ductile to brittle transition deformation. These results contribute to the better understanding of this north-western part of the Cameroon in relation to the deformation and plutonism.

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