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Structural Characterization of Outcrop-Scale in Edea and Eseka Area: Evidence for a Complex Polyphase Deformation in the Paleoproterozoic Nyong Serie (Congo craton-South Cameroon)

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Abstract: *The Edea and Eseka area belongs to the Nyong Series which is the north-western extension of the Congo Craton in Cameroon. Structural analyses were carried out in this region in order to delineate the tectonic evolution. The structures of this area are the result of a complex structural evolution and the area experienced a polyphase deformation resulting to a succession of several phases of deformation. Detailed information on the structures and the relative timing of deformation are as follows: (1) an early stage (pre- D_1) phase corresponds to the relicts of an early schistosity preserved as inclusion trails in garnet and pyroxene crystals, immediately followed by (2) two main stages (D_1 and D_2). D_1 evolved in tangential movements, it is typically ductile and characterized by a regional-scale S_1 mylonitic foliation associated with F_1 folds and a sub-horizontal stretching lineation L_1. D_2 is the main deformation phase due to the diversity of its structures. The deformation style of the D_2 phase is heterogeneous affecting the previous D_1 fabric by transposition, and evolved in a trans-current tectonic regime. The late- D_2 deformation phase is underlined by brittle features. At the regional scale, the chronology of the deformational phases in the Nyong serie is still controversy. The structural evolution of the Nyong serie in Edea and Eseka area has similarities with the Ogooué metamorphics in Gabon and the Trans-Amazonian belt in Northeast Brazil. Therefore the Nyong serie is correlated with the collision belts (Ogooué metamorphics) of about the same age on the eastern margin of the Congo craton and with the Trans-Amazonian Orogenic Belt.*

Key words: *Edea and Eseka area; Nyong series; Congo craton; tangential movements; transcurrent tectonic regime; Ogooué metamorphic; Trans-Amazonian belt.*

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I. Introduction and General geology

In central Africa the structural evolution of the continental crust is dominated by several tectonic events: the Archaean orogeny (3.0-2.5 Ga), the Eburnean or Paleoproterozoic orogeny (2.2-1,8 Ga) and the Pan-African orogeny (600-500 Ma). In Cameroon the Paleoproterozoic terrains have been reported mainly in the Ntem complex, and also occur as relicts within the Neoproterozoic formations[1]. Paleoproterozoic terrains of the Ntem complex in Cameroon are known as Nyong series [1,2,3]. The Edea and Eseka area (Fig. 1) is located in this serie within the Congo craton. The North-Western corner of this craton in South Cameroon refers to the Ntem Complex [4,5,6], which is bordered in the north by the Yaoundé Group [7,8,9,10] of the Pan-African orogenic belt in central Africa. The Ntem complex is divided into two main structural units: the Nyong serie, to the northwest end, and the Ntem unit, in the south-central area. The Ntem unit is dominated by massive and banded plutonic rocks of the charnockite suite and by intrusive tonalites, trondhjemites and granodiorites (TTG), dated at 2.9 Ga [2,11,12].

The Nyong serie in the NW corner of the Congo craton is a well-preserved granulitic unit of the West Central African Belt resting as an Eburnean nappe on the Congo craton [2,13]. The Nyong unit consists of metasedimentary and metavolcanic rocks, syn-to late-tectonic granitoids and syenites [14,15]. It displays three groups of ages [2,3,12,16]: (1) Archaean ages (2500–2900 Ma); (2) Palaeoproterozoic (2050 Ma) and (3) Neoproterozoic ages (626 ± 26 Ma). The high-grade metamorphism associated with arrested charnockite formation is dated at 2050 Ma[2]. The recent works of[1] indicate in this unit the Palaeoproterozoic ages for the granulitic metamorphism ranged between 1734 ± 22 Ma and 1893 ± 43 Ma (Th-U-Pb EMP-dating on monazites), they are interpreted as the ages of the granulitic metamorphism, contemporaneous with the charnockitisation and the emplacement of igneous protoliths. New Pan-African ages for the amphibolite metamorphic facies have also determined and ranged between 577 ± 2 Ma-677 ± 36 Ma (Th-U-Pb, EMP-dating on monazites[1]). These ages correspond to the melt and the emplacement of the sedimentary protoliths. The Ages of 1969 ± 170 Ma of charnockites represent the Eburnean cooling[17]. The Nyong unit includes some Archaean parts of the Ntem complex that were reworked during a Palaeoproterozoic event, and new Palaeoproterozoic material that was accreted to the Archaean craton.

The main structural characteristic of the Nyong series refers to the Kribi-Campo Shear Zone (KCSZ[5,12,13,18]. The KCSZ is a Precambrian mega dextral shear zone [19,20], well studied from Kribi towards the south (Campo). The Edea and Eseka region located in the Nyong serie (western border of Ntem complex in Congo craton) shows very conspicuous and spectacular examples of deformation at the outcrop scale. Therefore this paper presents the structural characteristics of the deformation.

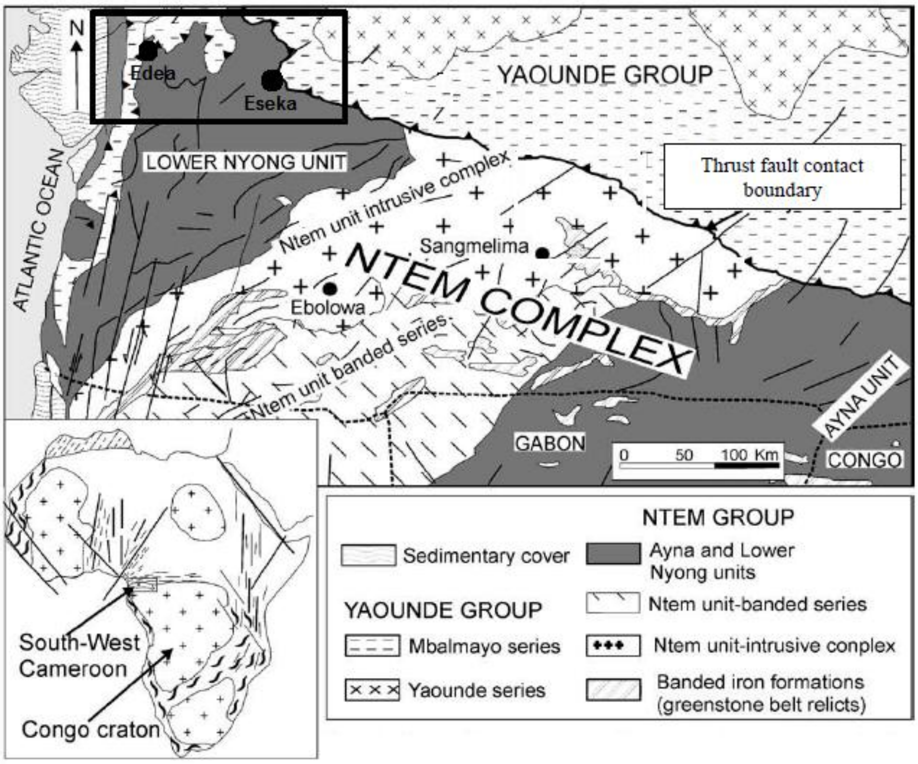

Figure 1: Geologic map of South-West Cameroon [14,21] as modified from[5] showing the lithologic units of Ntem Complex or Congo craton in Cameroon and the studied area (Edea and Eseka).

II. Methods

The exploration method used in this work is a field survey based on the search and localization of outcrops with the help of the topographic map, and the Global Positioning System (GPS). In order to make this field campaign a successful, we used the following steps: (i) we moved round the study area searching for rock outcrops from which information and structural measurements have been collected, these measurements have been carried out with a compass clinometers and took into consideration the orientations of the structural elements, their extension and the characterization of these elements; (ii) photographs of the outcrops were taken from different angles; (vi) the samples were characterized insitu. In the laboratory the readings of structural measurements have been plotted in the lower hemisphere of Schmidt net using the Stereonet software in order to determine the major directions of structures.

III. Results

III. 1. Brief lithology

Lithologicaly and according to Ndema Mbongue et al (2014) and Ndema Mbongue (2016), the study area comprises (i) a unit of meta-igneous rocks (pyroxene-gneiss, charnockitic gneiss, garnet-charnockitic gneiss, biotite-gneiss, amphibole-biotite gneiss, garnet-amphibole gneiss, pyribolite, pyrigarnite and garnet-amphibolite), (ii) a metasedimentary rock unit (garnet micaschist mainly and schist) and (ii) the rocks resulting from the melt (they include migmitite and TTG).

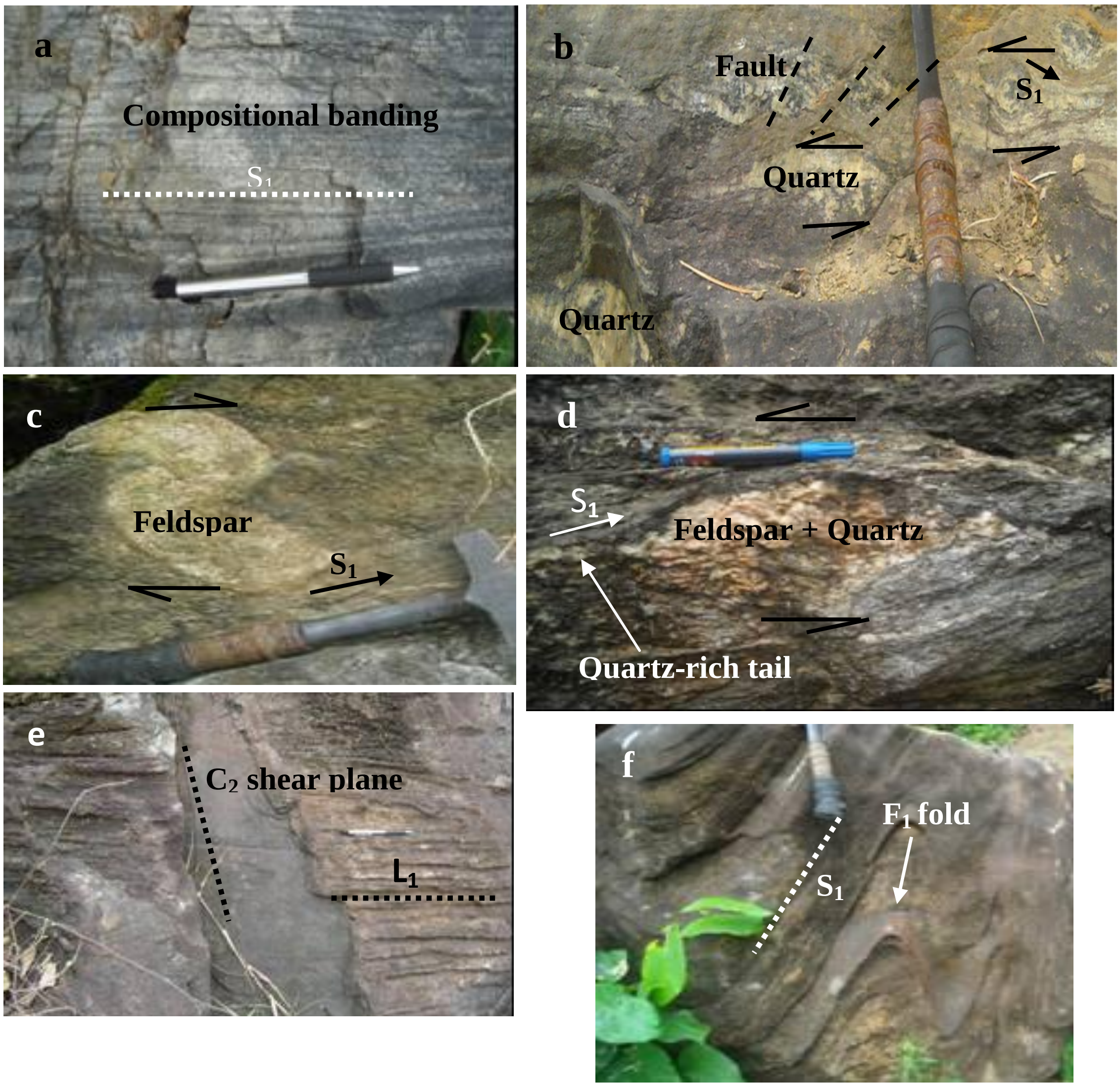

Figure 2: Photomacrographs for the structures of D_1 phase. (a) Compositional banding. (b) Boudinaged aggregate of quartz showing fault and δ-shaped structures as shear sense indicators. (c) Sigmoid-shaped feldspar with shear sense indicators. (d) lens-shaped feldspar + quartz crystal showing a symmetric shaped and a quartz-rich tail. (e) L_1 stretching lineation. (f) F_1 intrafolial fold display axial plane schistosity.

III. 2. Structural analysis

Many structures have been mapped in the basement metamorphic rocks in Edea and Eseka area and chronologically, they have been group into an early deformation phase pre-D_1 and two (02) main ductile deformation phases termed as D_1 and D_2. The D_2 deformational phase ends with the emplacement of late structures that characterize the late- D_2 phase.

III. 2.1. D_1 deformation phase

The D_1 deformation phase is recorded in pyroxene-gneiss, garnet-charnockitic gneiss, amphibole-biotite gneiss, garnet-amphibole gneiss, pyrigarnite and migmitite. It is characterized by: a S_1 foliation associated with L_1 lineation and the development of F_1 folds. The S_1 foliation is outlined by (i) a compositional banding (Fig. 2a), the thicknesses of the bands vary from millimeters to centimeters. The light bands contain minerals such as quartz and feldspars while the dark bands are rich in ferromagnesian minerals such as pyroxene, amphibole and biotite; (ii) a mylonitic schistosity S_1 is underlined by the preferred orientation of biotite, stretched quartz, boudinaged aggregate of quartz with sigmoid-shaped displaying fault (Fig. 2b), (iii) Large crystals of feldspars displaying sigmoid-shaped (Fig. 2c), and lens-shaped quartz + feldspar crystal showing a symmetric shaped and a quartz-rich tail (Fig. 2d). In the pyrigarnite, pyroxene-gneiss, garnet-charnockitic gneiss, garnet-amphibole and garnet-amphibole gneiss, S_1 minerals surround coronitic garnet and pyroxene crystals implying that these garnet and pyroxene are related to pre-D_1 phase. The attitude of the foliation is nearly constant in the study area. The foliation surfaces S_1 strike NE-SW and have gentle dips (0 to 15°) to the NW and to the SE direction. The poles to S_1 show a girdle distribution (Fig. 3) that implies subsequent folding around a gently NNE plunging axis.

The related lineation L_1 is conspicuous and corresponds to a stretching lineation (Fig. 2e). It trends NNE-SSW with a gentle plunge (0-10°) towards the NNE/SSW (Fig. 3). F_1 folds (Fig. 2f) are mainly upright folds, recumbent folds and intrafolial isoclinal folds, and they display S_1 as axial plane schistosity. The average fold axis trend is N25°E plunging between 2-20° in the SW and in the NE (Fig. 3).

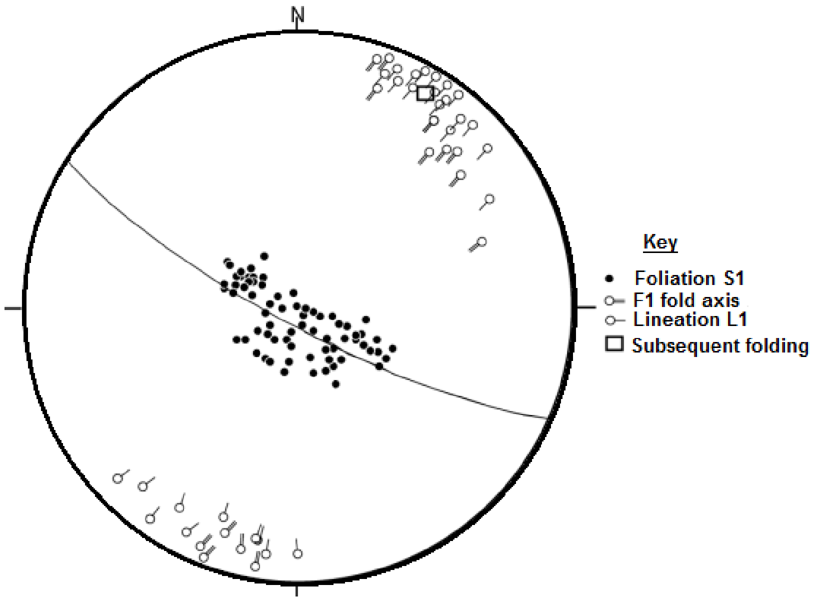

Figure 3: Stereographic representation of D_1 structures

III. 2.2. **D_2 deformation phase**

This tectonic phase is well-recorded in both the meta-igneous and metasedimentary rock units. It is characterized by a heterogeneous deformation affecting the previous D_1 fabric by transposition of S_1 foliation. D_2 deformation is associated with the development of S_2 schistosity, C_2 shear planes (Fig.4a), F_2 folds (Fig.4b) and β_2 Boudins (Fig.4c). The S_2 schistosity is an axial plane schistosity for the F_2 folds, It is linked to the shear and to the folds. The S_2 plane is defined by preferred orientation of quartz ribbons, ferromagnesian lamellaes, biotite and muscovite flakes. The attitudes of S_2 fabrics were measured and the stereographic projection reveals N100°E to N120°E (Fig.4d) dipping 50-75° toward the NE.

C_2 shear planes (Fig.4a) are more abundant, they appear as steep ductile zones that disrupt the S_1 foliation and they characterize sinistral and dextral movements. Their dip is no less than 10° and the average orientation is N125°E, 13°NE/SW (Fig.4d). F_2 folds admit S_2 as axial plane schistosity (Fig.4b); they include flanking folds linked to shear planes and displaying inversed limbs, and upright folds. Folds with inversed limbs are dissymmetric, they consist of western verging folds.

β_2 boudins (Fig.4c) include (i) complete boudins made up of quartz and feldspar enveloped by S_2 schistosity and displaying pinch and swell structures and (ii) incomplete boudinage made up of mafic minerals. The extensional value of the boudin axes varies between 10 and 48 cm for the long axis (L) and 3 to 4 cm for the short axis (S). L/S ratios ranging between 3/16 and 5/6 suggest flattened boudins of fold axis. The direction of the boudin axes range between N130°E to N-S, plunges are smaller than 20° (Fig.4d). As mentioned above, the D_2 deformation ends with the emplacement of late structures that characterize the late- D_2 deformational phase.

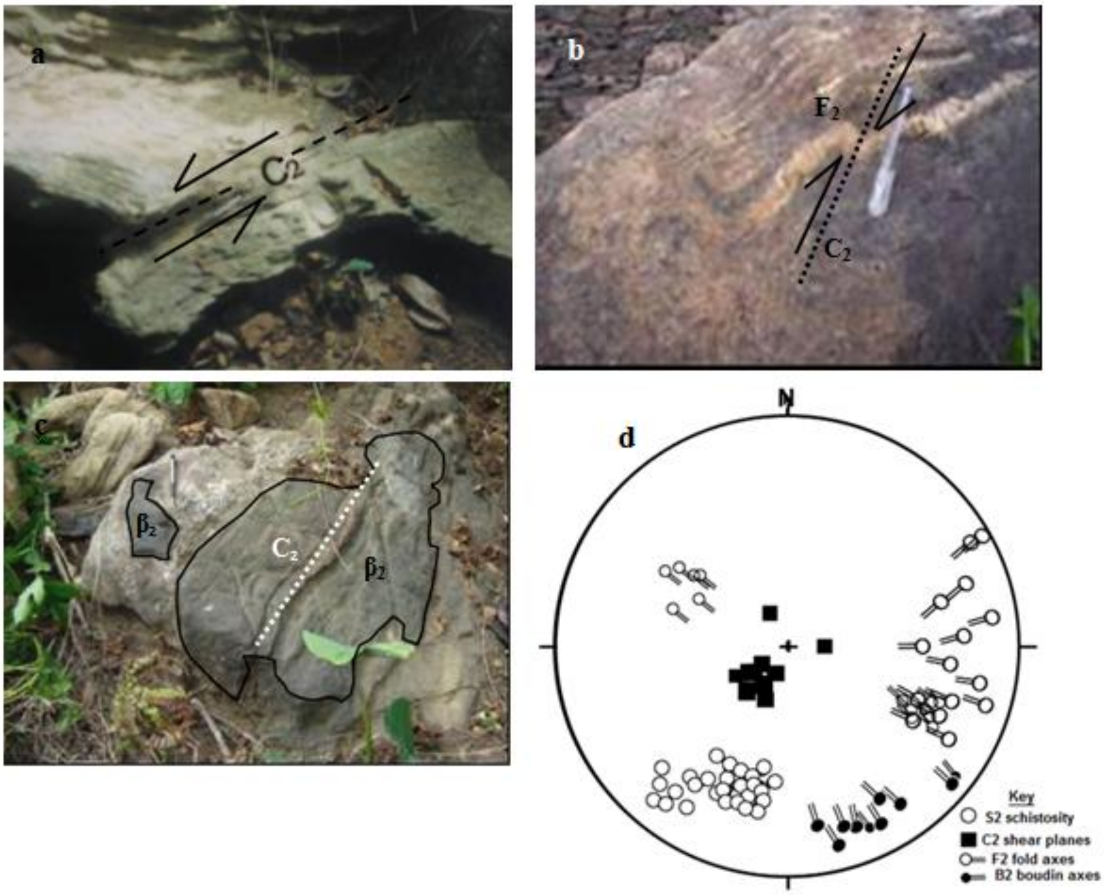

Figure 4: Structural elements for D_2 deformational phase. (a) C_2 shear planes; (b) C_2 shear plane and F_2 fold; (c) β_2 boudin displaying C_2 shear plane (d) Stereographic plot of D_2 structures.

III. 2.3. **The late- D_2 deformational phase**

The late- D_2 phase is highlighted by brittle features such as late shear planes C'_2, joints J'_2 and fractures F'_2. Late shear planes C'_2 (Fig. 5a) are mapped in pyroxene-gneiss and garnet-charnockitic gneiss. They are outlined by the conjugated late quartzo-feldspathic bands that cross-cut the structures of D_2 phase with a gentle angle (sub-parallel or secant to S_2). Some measured C'_2 planes strike approximately N-S and E-W and dipping 5 to 40°N.

J'_2 joints (Fig. 5b) are veins that are filled up with late recrystallization fluids. They are most often grouped into two sets generally oblique displaying rectilinear and parallel edges. The joints developed during the late- D_2 phase exhibit an average direction of N18°E and N25°E.

F'_2 fractures (Fig. 5c) occur as a result of tensile stress with rupture in the rock without displacement of compartments. They are developed in various directions and reveal two major sets that are obliquely secant. The two sets are sub-vertical to vertical and strike approximately N115°E and N120°E.

Figure 5: Photomacrographs for Late- D_2 structures. (a) C'_2 shear planes; (b) J'_2 joints and F'_2 fractures.

IV. Discussion

The Edea and Eseka area in the Nyong serie that is located NW margin in the Congo craton displays a complex and a polyphase structural evolution. This area is overprinted by an earlier pre-D_1 phase and two main phases of deformations namely D_1 and D_2. S_1 minerals surround coronitic garnet and pyroxene crystals implying they related to pre-D_1. Also S_1 surround large lenticular and sigmoid microlithons of quartz and feldspar; lenticular and sigmoid microlithons structures are mostly found in shear zone [22,24,2526].

D_1 deformation phase evolved in a tangential phase regime characterized by a flat or sub-horizontal S_1 mylonitic foliation, associated with a stretching sub-horizontal lineation and F_1 folding (upright, recumbent and intrafolial isoclinal folds). These characteristics also testify according to[27] to a thickening stage of D_1. S_1 foliation is dipping oppositely to the NW and to the SE and the attitude is nearly constant in the study area. The mylonitic foliation corresponds to the regional-scale foliation S_1 in the study area and in the entire Nyong serie. D_1 phase is responsible of the nappe stacking that was emplaced horizontally to form a classical fold-and-thrust belt[28]. The nappe vergence in Edea and Eseka area, deduce from transport direction toward the East, is different to that observed in Pan-African belt [29,30]. D_1 fabric has been progressively overprinted by D_2 deformation.

The D_2 tectonic phase is the main tectonic phase in the study area. It is characterized by a diversity of structural elements: (1) axial plane schistosity S_2 associated (3) with F_2 folds with different morphology; (4) abundant C_2 shear planes and (5) boudinage β_2. These structures result from a heterogeneous deformation affecting the previous D_1 fabric by transposition of S_1 foliation; therefore D_2 phase consists of a coaxial and rotational deformation evolved in a trans-current tectonic regime. The coexistence of folding and shearing in the Edea and Eseka area can be understood as the effect of deformation partitioning at mid-crustal depth [31,32]. Shear sense indicators are consistently dextral and sinistral and the D_1 and D_2 structures testify of a progressive deformation during the activity of a major ductile shear zone[33].

Late- D_2 is a phase of brittle tectonic with sub-vertical fractures, regional-scale joints and conjugated shear planes. In the Nyong Serie the Late- D_2 is also reported by [1,34,35,36]. However this Late- D_2 phase has been labeled as D_3 phase by [26,37,38]. Therefore at the regional scale, the chronology of the deformational phases in the Nyong serie is still controversy.

The Nyong serie in Edea and Eseka area whose structural evolution is polyphase and complex has structurally similarities with the Ogooué metamorphics[39] in Gabon and the Trans-Amazonian belt [40,41] in Northeast Brazil. In the study area, a pre-D_1 phase and two main phases of deformation (D_1 and D_2) have been recorded, and three phases (D_1, D_2 and D_3) in the Ogooué metamorphics and two phases (D_1, D_2) in the Trans-

Amazonian belt. The pre-D_1 corresponds to the relicts of an early schistosity preserved as inclusion trails in garnet and pyroxene crystals and does not have an equivalent in the Ogooué metamorphics and in the Trans-Amazonian belt. As far as the D_1 is concerned, the S_1 foliation describes in the Ogooué Serie [42,43] and in the Trans-Amazonian belt [44,45] has similarity with the regional-scale mylonitic foliation S_1 striking NE-SW reported in Edea and Eseka area. The D_2 tectonic phase is the main tectonic phase in all the three Series (Nyong, Ogooué and Trans-Amazonian). It is trans-current and ends with the late structures in Edea and Eseka area; whilst in the Ogooué serie D_2 is contemporaneous with the emplacement of the granitic Abamié Dome [42,43]. This tangential deformation indicates major crustal shortening in the collisional suture zone (Ledru et al., 1989). In the Trans-Amazonian belt, the second episode (D_2) evolved in a transpressional tectonic regime and its deformation geometric pattern is partitioned between a network of NNW-trending folded and steep-dipping oblique to strike-slip sinistral shear zone domains [44,45]. The kinematic indicators (S–C structures, asymmetric foliation trajectories and oblique to subhorizontal L_2 stretching lineations) outline tectonic transport from ESE toward WNW. In general, the geologic structures describe in the three series correspond to a part of a collisional N-S chain recognized in the Pan-African belt and in the Trans-Amazonian belt [46,47,48,49,50,51]. Therefore the Nyong serie is correlated with the collision belts (Ogooué metamorphics) of about the same age on the eastern margin of the Congo craton and with the Trans-Amazonian Orogenic Belt.

V. Conclusion

Field campaigns in Edea and Eseka area show different aspects that took in consideration structural elements at different outcrop scales and the results reveal that the structural evolution is complex and the area experienced a polyphase deformation.

The pre-D_1 phase corresponds to the relicts of an early schistosity preserved as inclusion trails in garnet and pyroxene crystals.

The D_1 deformation phase is typically ductile and characterized by: a regional-scale S_1 mylonitic foliation showing alternation of parallel compositional bands and lithological units, recumbent and intrafolial isoclinal folds, sub-horizontal stretching lineation, corresponded to tangential movements.

The D_2 is the main deformation phase due to their diversity of structural elements. It is linked to the shear and folds; the deformation style of the D_2 phase is heterogeneous affecting the previous D_1 fabric by transposition. It is characterized by the development of axial plane S_2 schistosity, abundant shear planes, upright and flanking folds F_2 and boudinage. The D_2 deformation phase consists of a coaxial and rotational deformation evolved in a trans-current tectonic regime.

The late- D_2 deformation phase underlined by brittle features such as sub-vertical fractures, regional-scale joints and conjugated shear planes. At the regional scale, the chronology of the deformational phases in the Nyong serie is still controversy.

The structural evolution of the Nyong serie in Edea and Eseka area has similarities with the Ogooué metamorphics in Gabon and the Trans-Amazonian belt in Northeast Brazil. Therefore the Nyong serie is correlated with the collision belts (Ogooué metamorphics) of about the same age on the eastern margin of the Congo craton and with the Trans-Amazonian Orogenic Belt.

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