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Preserved Sedimentary Features in the Pan-African High-Grade Metamorphic Rocks from the Yaoundé Series (Cameroon)

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Abstract The ortho- and paraderived metamorphic formations of the Yaoundé series belong to the southern domain of the North Equatorial Pan-African Fold Belt. Para-derived formations of granulitic facies, which, unlike the other granulitic domains in the world, still contain preserved sedimentary features. These include the lithological banding which constitutes intercalation of garnet and kyanite-rich gneisses and quartzites, sometimes bedded, this banding of sedimentary origin is accentuated by the D_1 tangential deformation which transposes the S_0 bedding into foliation; the P_1 intrafolial folds with horizontal fold axis and parallel to the bedding; lenticular structures marked by horizontal quartzite veins or boudins parallel to S_0/S_1 or $S_0/S_1/S_2$ foliations, intercalated between the garnet and kyanite-rich gneisses, and sometimes lenses of garnet and kyanite-rich gneisses intercalated between the quartzites. They are either syn-D_1 (quartzite or banded quartzite) sometimes transposing S_0 stratification, or syn-D_2 (quartzite, garnet-rich quartzite, granitic leucosome) linked to the in-situ partial melting of the garnet and kyanite-rich gneisses. The post-metamorphic and recent rock splitting, in contact with banded quartzite, quartzitic gneiss and other gneiss types, reflects an original pile of sedimentary formations of varied composition. The brittle (competent) behaviour of quartzite compared to the garnet and kyanite-rich gneisses which is rather ductile suggests the original pelitic nature for the garnet and kyanite-rich gneisses and sandstone for quartzites.

Keywords: *Sedimentary features, paraderived, Yaounde series, Cameroon*

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1. Introduction

Sedimentary structures are valuable elements in the reconstitution of deposit environments, this is the case for most post-orogenic sedimentary basin, Cretaceous basins [1,2,3]. In Cameroon [4] and some surrounding countries, as Congo [5,6], Central African Republic [7,8], Gabon [7,9], these sedimentary structures are still preserved in the Precambrian deposits spared from the Pan-African orogeny. These structures are also sometimes preserved in granulitic facies of paraderived metamorphic rocks. This is the case in the Yaoundé series related to the Pan-African orogeny. The North-Equatorial Pan-African Fold Belt [10] or Neoproterozoic Central African Orogenic Belt [11] represents one of the most important suturing orogens, as its deformation history is critical for the Gondwanaland reconstitution [11]. It is made up of juxtaposed rock Units of varying crustal levels that are considered to represent imbricate large, crystalline, south-directed Yaoundé nappes emplaced onto the Congo craton [10,12-18].

Inspite of indications of collisional tectonics such as intense migmatisation and high- pressure granulite [10,19], the existence of South-verging, large, crystalline Yaoundé nappes remains controversial because no clear evidence for either thrust faults or suture marking a north-south oceanic closure has yet been found in the area, and the nappes are inconsistent with a regional non-mylonitic flat-laying composite S_1/S_2 foliation [11].

Thus, our study area is located to the southern part of this Pan-African North Equatorial Fold Beld in the Yaoundé series [10,14], belonging to the Yaoundé group. In this region, several works have been carried out with the aims to constrain the origin or tectono-metamorphic evolution of these gneisses [10,11,20,21,22]. The studied outcrops of this series are paraderived granulitic facies rocks [10] made up of essentially kyanite and garnet rich gneiss. Despite their granulitic character, they are marked by some structures remembering their sedimentary origin.. The aims of this paper is to highlight the sedimentary protolith evidence of gneiss and quartzite of the Yaoundé series from observed structures, as tabular to sub-tabular bedding, lenticular structures, horizontal or interstratified fissures or fractures, lithological splitting and the difference of competence.

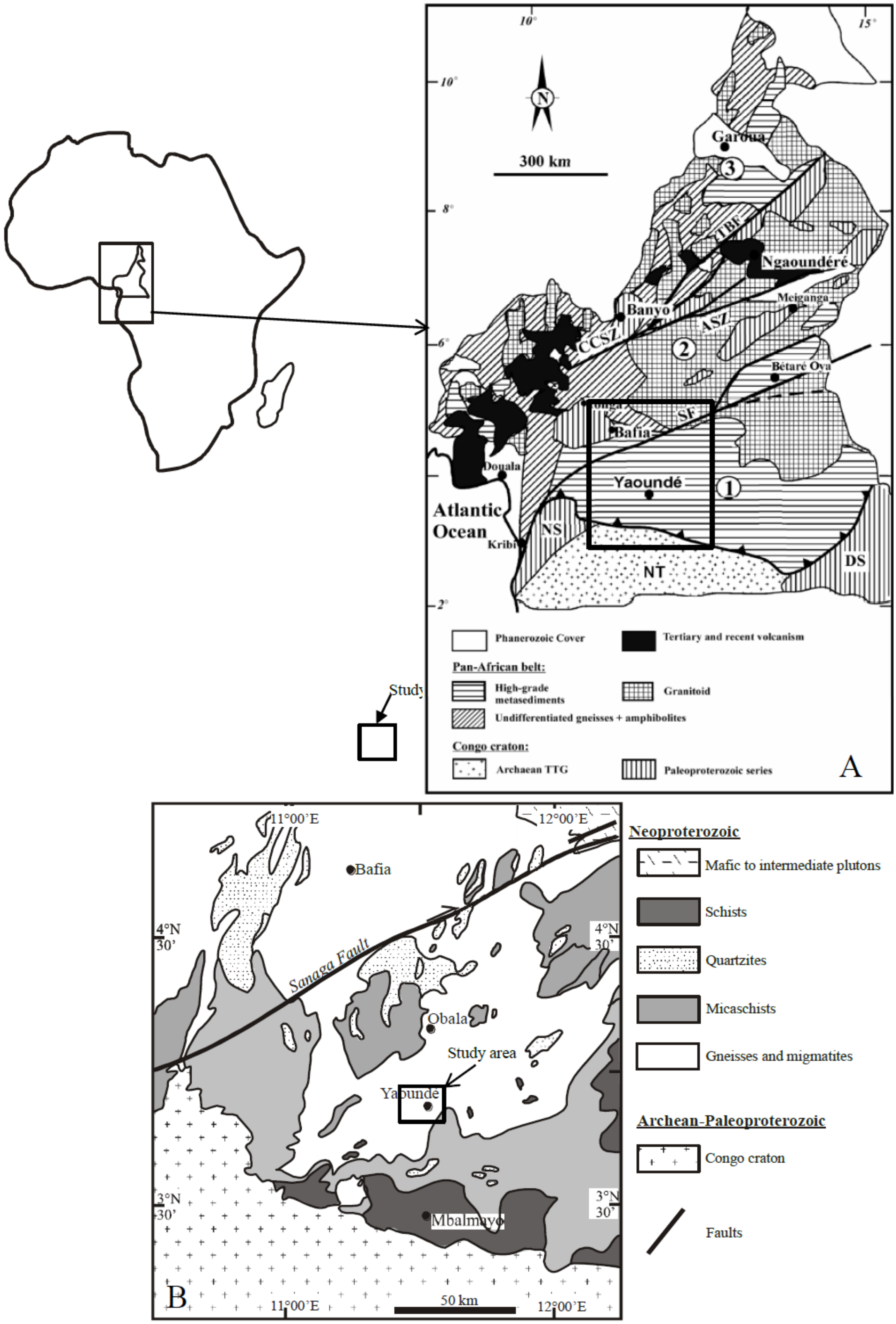

Figure 1. (A) Geological map of Cameroon [22] and (B) Geological map of South Cameroon showing the main rock units [11,23,24]; and the location of the studied area

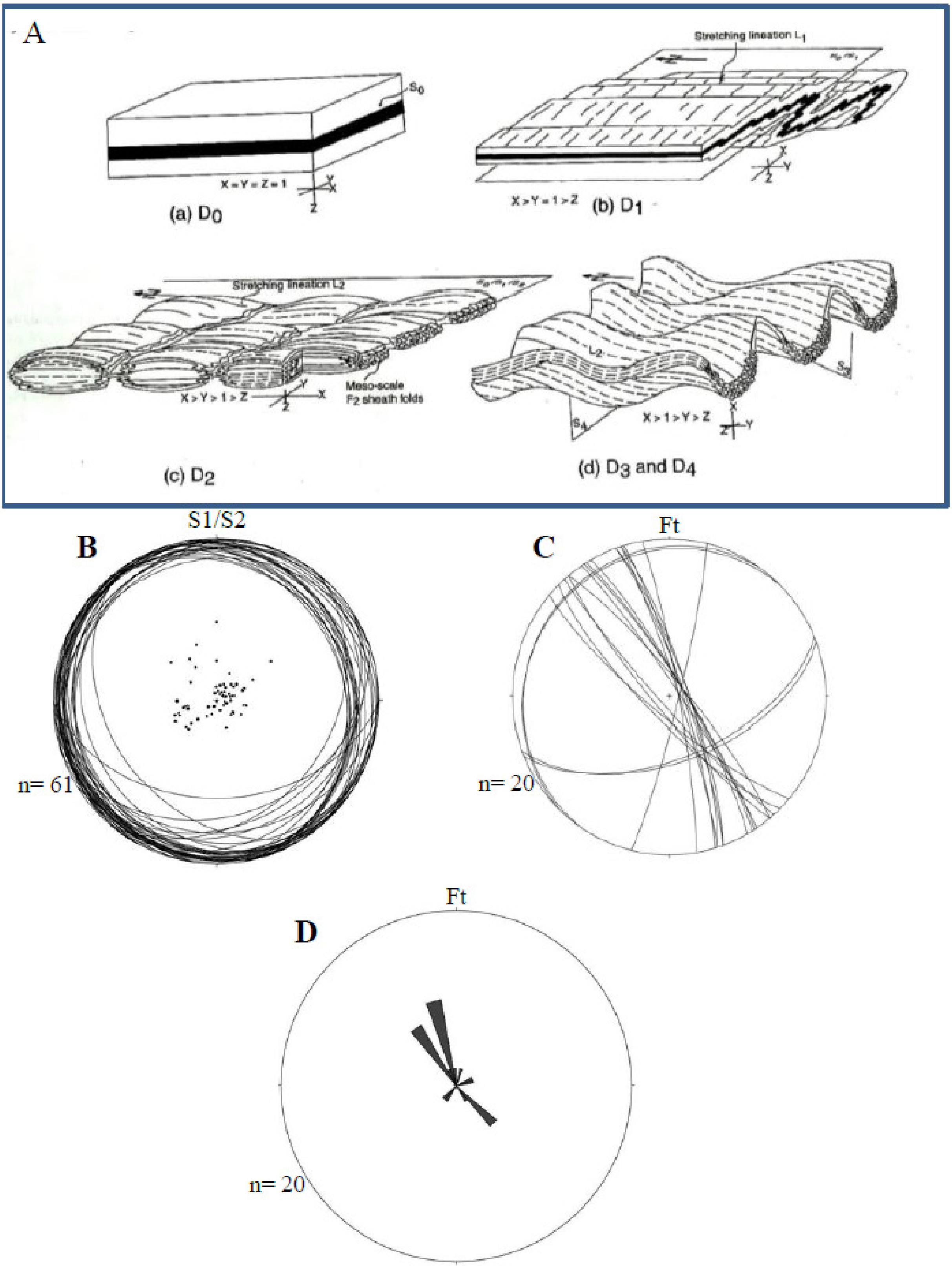

Figure 2. (A) Schematic models showing the different phases of deformation, D_0–D_4, [11] (B) Stereogram of foliation planes and (C-D) stereogram of fracture planes of the studied area

2. Geological Setting

The studied area (Figure 1b [11,23,24]) is located in the southern part of the Pan-African North-Equatorial Fold Belt in Cameroon [10] at south of the Central Cameroon Shear Zone [25]. It belongs to the Yaoundé series [10,16]. This series includes chlorite- rich schists, garnet- and (or) kyanite rich micaschistes, and garnet- and kyanite or garnet- and plagioclase or garnet and two micas rich high grade gneisses sometimes comprising lenticular levels or intercalation of calc-silicated rocks, marble, and quartzite [10,26], or interbedded with talcschist rocks [27]. Their protoliths are the sedimentary rocks that include pelites, greywackes, dolomite and evaporite with interstratified basic volcanic layers [10,26,28,29]. The metasedimentary rocks are locally intruded by meta-igneous rocks formed by pyriclasites and pyroxenites [10,30]. The protolith of the rocks from the Yaoundé series is composed of a mixture of Neoproterozoic and Paleoproterozoic sources [31,32,33,34]. The whole of the sedimentary sequence and the isotopic data suggest the existence of a continental basin or a shallow epicontinental environment on the northern edge of Congo craton [10,26,30,35], or a marginal back-arc basin that underwent collisional tectonic [19,28,34]. These rocks are commonly thought to have experienced a Neoproterozoic nappe tectonic event that is transpressional and responsible for thrusting the large Yaoundé nappe onto to Congo craton [16,17]. The rocks of this series have been affected by two major or main ductile deformation events D_1 and D_2 [10,11,30,37], D_1 laid to the formation of nappes that resulted in high pressure granulite metamorphism of soft sediments and D_2 is marked by a southern thrusting of the rocks onto the Archean Congo craton. They were further buckled by D_3 and D_4 folding phases (Figure 2A) [11]. To these ductile or folding phases, are associated ductile-brittle to brittle phases as C_2 and C_3 shear zones with either dextral or sinistral movements, and the D_4 phase characterized by various oriented joints and veins [38]. The conditions of paroxysmal metamorphism of the Yaoundé series are evaluated at 650 – 800°C and 9 – 12Kb [10,14,19,20,27,29,37].

The granulite facies or metasediment of the Yaounde series have been metamorphosed at 620 ± 10 Ma (U-Pb age zircon [31]) or at 616 Ma (U-Pb age on zircon and Sm – Nd [32]) and between 613 ± 33 Ma and 586 ± 15 Ma (Th - U – Pb age on monazite [39]. The leucosomes was melting between 592 – 558 Ma (U – Th – Pb monazite ages) and between 626 – 654 Ma (U – Pb zircon ages), and the metasediment (host rock of leucosomes) reveals the overprinting of Pan-African age, around 911 Ma (U – Pb zircon age) and of Palaeoproterozoic age, around 2127 Ma (U – Pb zircon age) [22].

3. Methods

Field works consisted in the identification of the different structural elements and recording their structural attitude (strike, dip, and dip direction) in the para-derivated gneisses, followed by sampling of the different rock facies. A chronological analysis of these elements was subsequently established. Twelve thin sections were manufactured at the LTM Nkolbisson Laboratory (Cameroon) and studied under polarized microscope at the Laboratory of Petrology and Structural Geology in the University of Yaoundé 1, Cameroon.

4. Results

4.1. Bedding

Bedding constitutes, from place to place, either banded quartitze (Photo G, Figure 3), or an intercalation of kyanite and garnet- rich gneiss, quartzite and leucocratic gneiss (Photo F, Figure 4) with a varying thickness of either quartzite from 3mm to 10 cm, and leucocratic gneiss from 3 to 17 cm and that of kyanite and garnet-rich gneiss are pluricentrimetric to plurimetric. The disposition of the beds are either repetitive (only quartzite or quartzite and gneiss) or composite (quartzite, garnet and kyanite-rich gneiss and leucocratic gneiss). Generally, they have gentle dip (0 - 20°). The mineralogical composition of the garnet- and kyanite- rich gneiss is as follows: Garnet (10 –30 %) kyanite (5 -10%) with other minerals such as biotite (10 – 15%), feldspars are dominated by microcline (10 – 20%), quartz (60 – 65%), rutile <1%) and muscovite <1%, generally displaying a granoblastic microstructure, oriented and heterogranular sometimes with granolepidoblastic tendency. Meanwhile leucocratic gneiss (dominated by quartz with a proportion of 60 – 65%, with garnet, <1.5%; kyanite, 2% and 3%; biotite, 3– 5%; muscovite, < 1%; feldspath dominated by microcline 15 – 25%; rutile, 1<%) and quartzites display an oriented granoblastic heterogranular microstructure. Grain size is variable, fine to medium (quartzite and leucocratic gneiss), and medium to coarse (kyanite- and garnet-rich gneiss).

4.2. Lenticular Structure with Pseudo-boudins

The lenticular structure is underlined either by quartzite veins sometimes sigmoid (Photos A and B, Figure 3) intercalated within the garnet and kyanite-rich gneisses, of pluricentimetric to decimetric thickness, and of metric to plurimetric length, the lenses of kyanite and garnet-rich gneisses (Photo F, Figure 3) intercalated within the quartzites, of centimetric to pluricentimetric thickness and pluridecimetric length and the pluridecimetric lenses or pseudo-boudins of garnet-bearing quartzite within the garnet and kyanite-rich gneisses (Photo E, Figure 5). These lenses are all parallel to the foliation or banding, and the contact with the host is generally sharp.

4.3. Lithological Splitting

The phenomenon of lithological flaking (Photos C and E, Figure 3) is quite conspicuous and can be observed either in contact with facies of different mineralogical composition (garnet-kyanite-rich gneiss and leucocratic gneiss or quartzite), or between the bedded quartzite bands. The cleavage surfaces or planes are sharp.

4.4. Difference in Competence

Locally, the outcrops of garnet and kyanite-rich gneisses with quartzite beds or veins show different deformation behaviour (Photos B and D, Figure 3). The quartzite bands are affected by vertical and horizontal fracture networks which almost or not affect the gneissic surrounding, thus highlighting the process of competence associated to the difference in the nature of the facies. If the origin or genesis of these two types of fractures is questionable, the average trend of the vertical fracture plane network corresponds to that of the major average trend of the fractures affecting the entire study area.

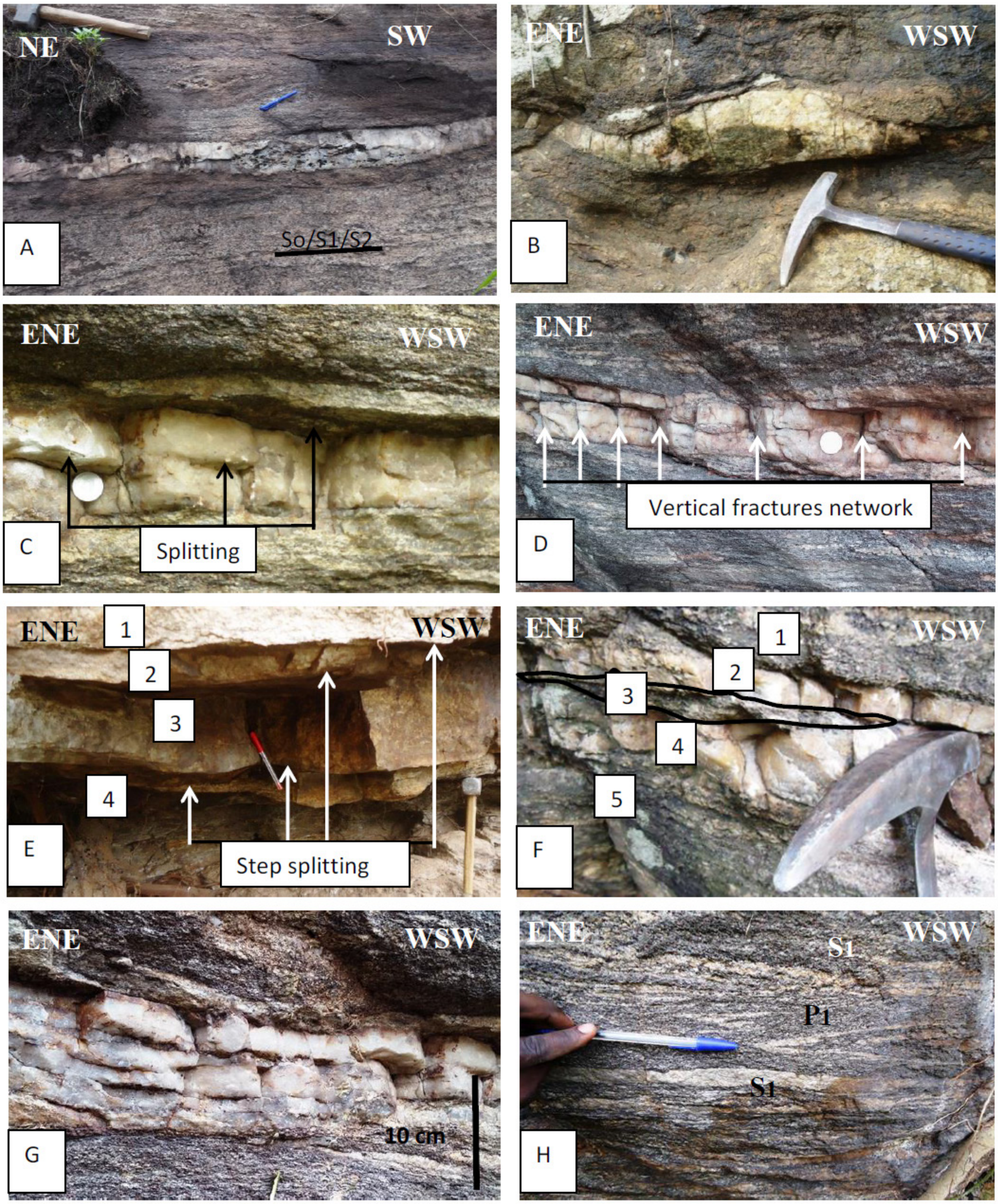

Figure 3. Field photographs of different identified structures, A: Fractured quartzite vein in the kyanite and garnet rich gneiss; B: Fractured and sigmoid lenticular quartzite in the kyanite and garnet rich gneiss; C: Spliting affecting banded quartzite and gneiss; D: Vertical fracture network; E: Level splitting affecting various gneiss (1 and 3: leucocratic gneiss, 2 and 4: garnet and kyanite-rich gneiss); F: Lenticular gneiss interbedded in the quartzite, and the whole are interstratified in the gneiss (1 and 5: garnet and kyanite rich gneiss, 2 and 4: quartzite, 3: garnet and kyanite-rich gneiss lenses; G: Banded quartzite interstratified in the Kyanite and garnet rich gneiss (S_0/S_1); H: Network of P_1 intrafolial fold with horizontal axis associated with S_1 foliation

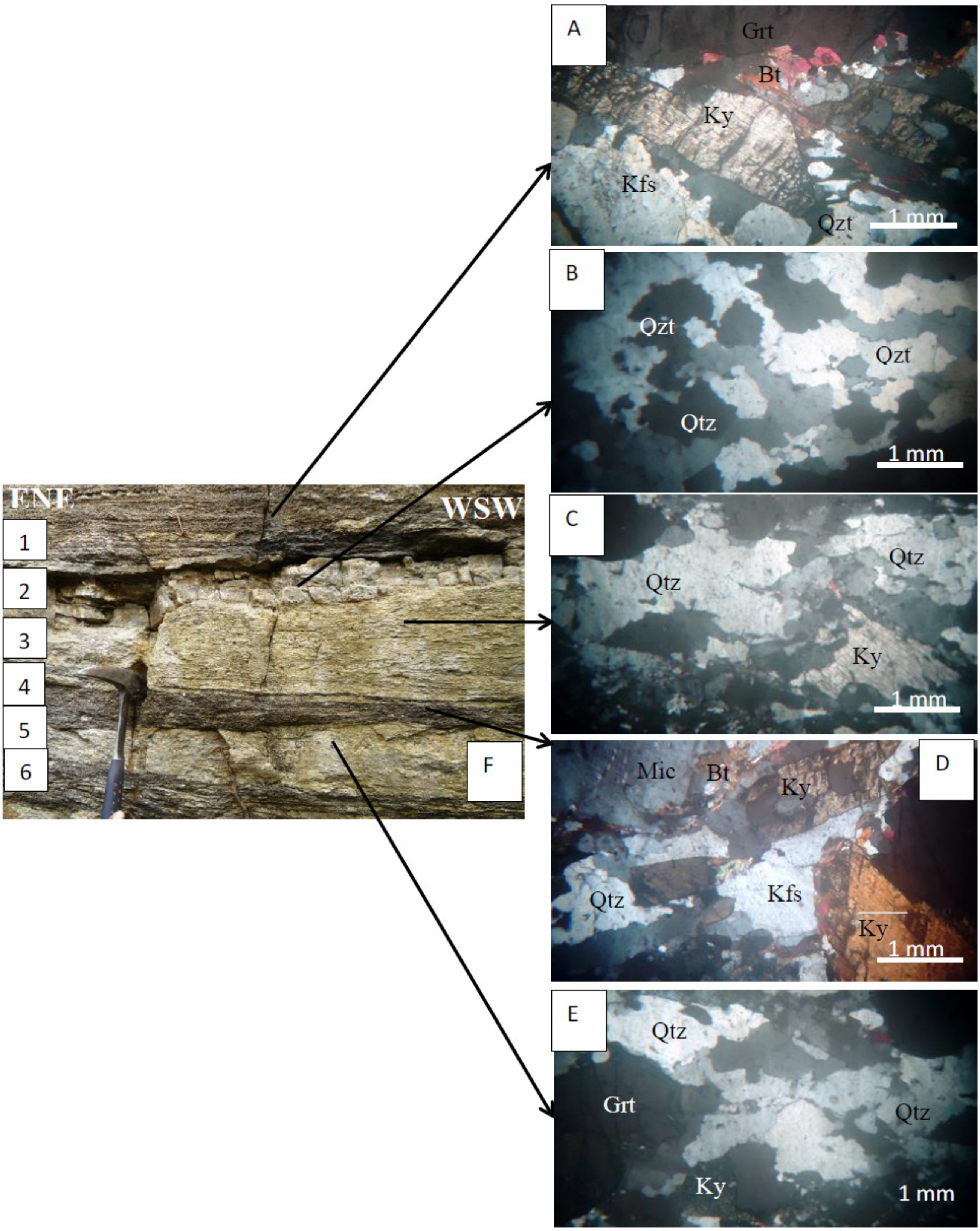

Figure 4. Field and microstructures photographs; A, B, C, D and E: oriented granoblastic heterogranular microstructure photographs (PL); F: vertical banded metamorphic rocks; 1, 4 and 6: Medium to coarse grained kyanite and garnet rich gneiss; 2: Fine to medium grained banded quartzite; 3 and 5: Medium grained leucocratic gneiss

5. Discussion

The low dip in bedding or foliation of granulitic formations (Para- and ortho- derives) in Yaoundé is attributed to tangential deformation D_1 [11,16]. Garnet and kyanite-rich gneiss are of sedimentary origin with pelitic protolith [10,21,22], affected by granitic leucosomes associated to the in-situ partial melting of metapelites, and injected linked to the melting of greywakes [22]. However, field and petrographic data show that bedding is sometimes repetitive or composite (garnet and kyanite rich gneisses, leucocratic gneisses, quartzites) and with grains of variable size, on the other hand, this bedding is clear in the para-derivated rocks contrary to ortho-derivated rocks. Furthermore, in addition to the intra-folial folds (Photo H, Figure 3) with horizontal axis parallel to bedding, the presence of quartzite bands intercalated between the garnet- and kyanite- rich gneisses represent the elements in favour of a sedimentary origin of these facies, as well as their sub-horizontal to horizontal attitude which would be original accentuated by the tangential tectonics D1. The stereogram of the foliation planes S1/S2 (Figure 2A) does not only display a gentle dip, but also that they are folded during D3 or D3/D4 deformation phases.

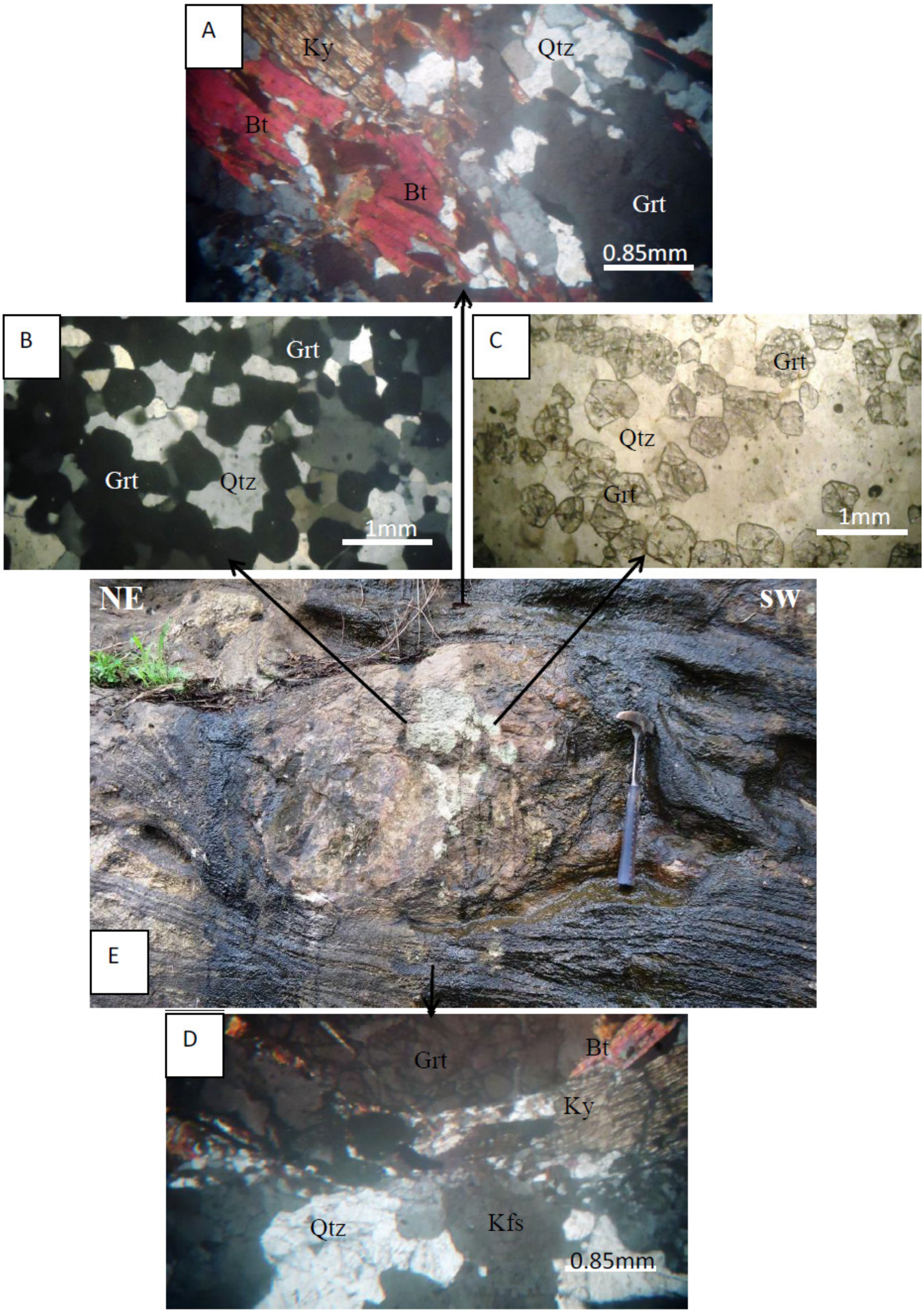

Figure 5. Field and microstructure photographs A: oriented grano- to granolepidoblastic heterogranular microstructure (Garnet-kyanite-mica gneisses); B and C: Granoblastic more or less isogranular microstructure (garnet quartzite, A: PL; B: PPL); D: oriented grano- to granolepidoblastic heterogranular microstructure (Garnet-kyanite-mica gneiss); E: Elongated boudin of garnet rich quartzite in the garnet-kyanite-mica gneisses

Garnet and kyanite-rich gneisses are generally intercalated, as noted above, by quartzite veins and attributed to syn-D2 melting [16,22]. These veins are either in situ, parallel to the foliation, or injected, not parallel to the foliation, of granitic composition, and more recent, Neoproterozoic, than the host or surrounding rock, Neo- to Mesoproterozoic [22]. New data and petrographic analyses show that garnet- and kyanite- gneisses are also intercalated by garnet quartzite veins and pure quartzite, and are always parallel to the foliation. The fact that these veins are of variable mineralogical composition, parallel to bedding or foliation, may therefore be linked on the one hand to in situ fusion according to the S0/S1 stratification plane, and on the other hand to in situ metamorphism of old sedimentary lenses (veins or lenses of arenaceous facies intercalated within the clayey facies). These structures are almost always present in non-metamorphosed Cretaceous sedimentary formations; sand or sandstone lenses in the clay layers or the reverse [1,3,40,41].

The splitting that affects both gneisses and quartzite bands intercalating each other points to an original pile of sediments of different mineralogical composition, alternations of pelitic and sandy facies affected by a metamorphism with the preserved original bedding.

Finally, the diverse behaviour of the brittle deformation (vertical fractures) observed between the intercalated gneisses and quartzites is related to the lithological difference, although the two formations belong to the same granulitic facies, and the ductile nature of the pelitic protolith of the garnet and kyanite gneisses would have influenced these gneisses. This brittle deformation is recent according to its association with the major fractures, with the average trends of N155°E (Figure 2C and Figure 2D) that affects the entire study area, and these fractures occurred as a result of the relaxation of tectonic stresses during the Plio-Pleistocene exhumation of the Yaoundé massif [42]. If vertical fractures are the expression of relaxation of tectonic stresses, interstratified (horizontal) fractures would be syn-metamorphic related to sediment piling during burial.

6. Conclusion

The metasediments of the Yaoundé series, although belonging to the granulitic facies, still retain structural elements recalling their sedimentary origin such as:

- Horizontal to sub-horizontal bedding or foliation (S_0/S_1 or $S_0/S_1/S_2$);
- P_1 intrafolial folds with horizontal fold axis;
- The lenticular structures underlined by veins and boudins parallel to the bedding or foliation linked on the one hand to the partial in situ fusion of the metasediments (Syn-D_2), and on the other hand, undoubtedly, to the metamorphism of old pelitic and arenaceous lenses (Syn-D_1) sometimes transposing S_0;
- The lithological splitting indicating on the one hand, a stacking of the original materials of different mineralogical composition and on the other hand syn-sedimentary weakness planes to D_1 phase;
- The phenomenon of rock competence indicates the original pelitic nature of garnet- and kyanite- rich gneisses and sandstone nature for quartzites.

Finally, the fracturing affecting these formations is recent and related to the relaxation of stresses during the exhumation of the massif.

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