Deformation and metamorphism in the central part of the Ngovayang Massif (South Cameroon)

François B. Ndong, Sylvestre M. Ntomba, Divine B. Okia, and Joseph O. Mvondo

Abstract - The Ngovayang massif is part of the major tectonic formations in the Nyong Series in southern Cameroon. Its tectonic history is characterized by three deformation phases that developed during the Archean to early Pan-African period. The D_1 phase is responsible for the S_1 foliation and the P_1 fold. Phase D_2, considered as the major phase of deformation, is syntectonic. It generated S_2 schistosity with a general NE-SW direction and NW dip. The S_2 schistosity has an axial fold plane P_2 and bears a lineation L_2. The D_3 deformation on the other hand is post tectonic and discontinuous. The main metamorphic imprint is related to the D_2 deformation phase, characterized by a high grade of metamorphism (amphibolite facies superior to granulite facies).

Keywords: Cameroon, metamorphism, Ngovayang, tectonic

INTRODUCTION:

A segment of about 100 km in length, The Ngovayang massif covers the localities of Eséka, Lolodorf and Bipindi in the south of Cameroon (figure. 1). This gives it the merit of being the most prominent of the Nyong unit massifs. It is oriented in the NE-SW direction whose extensions start from Songbadjeck (in the north-east) to the mountain of elephants (in the south-west) (figure 1). Its structure and morphological configuration which are not yet well known are probably linked to different tectonic processes associated to the collision of the Congo craton with Sao Francisco in Brazil (Figure 2*)*. The aim of this article is to reconstruct the tectonic history as well as the relationship between deformation and metamorphism in the central part which crops out in this part of the Ngovayang massif (figure 3).

F. B. Ndong is Assistant Research with the Institute of Recherches Geologique et Miniere, PO-Box 4110 Nlongkak Cameroon (corresponding author to provide phone: 0023796564599; e-mail: fndongbidzang@yahoo.fr).

S. M.Ntomba, was with Department of Earth Sciences and Universe, University of Yaounde I, Yaounde – Cameroon, PO.Box 912 Yaounde – Cameroon. He is now Assistant Research with the Ministry of Scientific Research and Innovation, Yaounde Cameroon (e-mail: sylmanto@yahoo.fr).

D. B. Okia is Senior Geologist with the ETS Geological Assistance, Yaounde Cameroon (e-mail: geologicalassistance@yahoo.fr).

J. O. Mvondo is Associate Professor, Department of Earth Sciences and Univers, Faculty of Sciences University of Yaounde I, Yaounde, Cameroon (e-mail: geologicalassistance@yahoo.fr).

II- METHODOLOGY

The deformation history proposed by the central part of the Ngovayang massif is based on numerous geological field trips and microstructural analyses carried out between localities of Lolodorf et de Bipindi in the south of Cameroon. Structural analysis was mainly carried out in metamorphosed formations.

This work is a complement of previous work traces a brief structural history of the study zone. It is first carried out in the field through observations, description and summary interpretation of results. In the laboratory, field data (attitudes of planes and lines) was plotted and analysed using specialised GIS softwares; Spheristat 3.1, Geoplot, Stereonet … with which an average attitude was obtained, the compression which prevailed in the zone, fold axis not observed in the field and the direction of deformation. Microscopic observations were done with OPTIC IVYMEM SYSTEM binocular microscope which helped us to determine with precision the principal phase minerals in equilibrium (Parageneses) and to give a chronology to different mineral in relationship metamorphic events.

III- RESULTS AND DISCUSSION

A- Geological context.

The Ngovayang massif is an eburnean orogenic formation linked to the collision between the Congo craton and Sao Francisco in Brazil circa 2.32 Ga. Former work carried out in the southern part of Cameroon where the Ngovayang massif crops out are summarised in the works of **[7]** and [8]. Let us consider the works of [8] which led to the establishment of the geological map of south west Cameroon (figure 4*)*. It delimits three orogeneses respectively produced from the Archean (Liberian orogenesis), to the palaeoproterozoic (eburnean orogenesis) and to Neoproterozoic (Pan-African orogenesis). Structurally, they define three deformation phases D_1, D_2 and D_3. According to these authors, the eburnean formations are affected by an S_2 schistosity, an L_2 lineation and a C_2 sheering whose geometric organization calls in mind the zones of sinister wrench fault. The studies carried out by [10], based on U-Pb and Sm-Nd methods shows that the conception of an Archean craton

(Ntem group) restructured in the north and north west border to give the Lower-Nyong unit should could have been replaced by that of two units of different ages. The Ntem complex belonging to the Archean age and the Lower-Nyong series of Eburnean age. The latter was formed during the Lower Proterozoic (~2900 Ma) following the collision of the Congo craton with that of Sao Francisco in Brazil. They interpret the Archean (~2900 Ma) ages of this unit as those of the protolithic and not as the ages of the putting in place. On the bases of geochemical and petrographic studies [11], shows that the Eséka migmatites were remobilized at high temperature and pressure during the Palaeoproterozoic and the Neoproterozoic. [12], show a model the petro-structural evolution of the Eséka-Makak sector integrated in the Lower Nyong and Lokoundjé units. This sector is made of gneissified TTG (Tonalite, Trondhjemite, Granodiorite) supracrustal formations and mica-schist. It can be concluded that, the Lower Nyong unit corresponds to the restructured and remobilised north western border of the Congo craton. [3], in trying to better understand the Eburnean orogeny discusses the relationship between metamorphism, deformation and plutonic activities at the contact between Archean and palaeoproterozoic. He defines two models; an accretion model where juvenile magma generated by partial fusion after the recycling of the crust, produces plutons whose putting in place leads to a progressive growth of a new lithosphere. The uprising of these plutons causes the deformation and metamorphism of older rocks. The second model shows that the convergence of crustal blocks is at the origin of forces which give rise to the Eburnean deformation.

B- Deformation History

According to the collected data, the history of the Ngovayang chain comprises of three deformation phases (D_1, D_2 and D_3). The age of implicated deformation shows that the deformations were produced from the Archean to the start of the Pan-African. In more details, the main characteristics of the deformation phases are as follows:

- First deformation phase D_1

It is responsible for folding P_1 and foliation S_1. The primitive surface S_0 corresponding to the original stratification was transposed by phase D_1 to surface $S_{0\text{-}1}$. In garnet and biotite bearing metabasites. The S_1 foliation is accentuated by the alternation of light coloured layers (quartzo-feldspathic) and dark coloured layers (ferromagnesian). it is marked by an average attitude N049E. 27NW. The assemblages of metabasites formations in the region thus observed show that this foliation often has boudins and underwent a flattening P_3 which undulated it (figure 10a). The P_1 flattening which developed in the metabasites is characterised by symmetric isophase folds and axial trace which is parallel to S_1 foliation.

- Second deformation phase D_2

The D2 phase, considered as the main deformation phase, corresponds to regional deformation. It is penetrative and comprises of different distinct events. The S_2 schistosity, the P_2 axial plane of folds is a carrier of L_2 lineation. This schistosity has a general direction of NE-SW and dips to the NW. The data projection of their attitudes in the Schmidt's canevas lower hemisphere shows an average of N046E.53NW at Bikalla (figure 5), N048E.30NW at Mougué (figure 6), N051E.37NW at Mbikiligui ***(***figure 7***)*** and N040E.29NW at Molombo (figure 8). This data perfectly shows the transition from S_1 to S_2. The stretch lineations (biotite, quartz) all have a steep plunge towards the N of the average attitude N139E.24NW (figure 9). The P_2 folds always of axial traces are symmetric and dissymmetric and affect all the rocks of the region. They are isoclinal locally having the appearance of open folds, sub-right, asymmetrical and haphazard vegence (haphazard orientation). Meanwhile their formation is not accompanied by the development of new foliations and are thus caused by the folding of schistosity S_2 ; illustrated stereographically by the distribution of S_2 poles in a large circle of direction N143E.71NE at Bikalla (figure 5), N140E.85NE at Mougué (figure 6), N060E.37SSE at Mbikiligui ***(***figure 7***)*** and N033E.29SE at Molombo ***(***figure 8***)***. These folds are induced by double compression NW-SE and NE-SW ***(***figure 9***).*** Shearing is not intense in the region. It is ductile and fragile-ductile of average orientation N155 sinister (figure 10b). It reverses the $S_{1\text{-}2}$ foliation and tends to be parallel in the middle where schistosity and shearing merge thus creating the S/C (figure 10d) planes. B_2 Boudins are formed by quartz veins and amphiboles. They are pinch and swell which are asymmetrical and parallel to $S_{1\text{-}2}$ regional foliation ***(***figure 10c***).*** The elongation axis is generally NE-SW. The D_2 deformation phase corresponds to double stretching, illustrated on the field by observation in the XZ and YZ of B_2 boudins planes.

- Third deformation Phase D_3

The third deformation phase is a bit late and takes place in two episodes; in initial D_{3a} episode characterised by very intense zones of shearing, more or less large, shown by mylonitic schistosity S_3 of average pole 230/47° which brutally S_2 cuts foliation and P_3 folds. P_3 folds are of regional calibre and are observed in the form of accompanying folds (drap fold) $S_{1\text{-}2}$ (figure 10a) of axial plane N086E.17W. These folds create a sort of crenulation whose axis is parallel to L_2 lineation and undulating all the structural systems. A terminal episode D_{3b} characterized by shear planes C_3 ***(***figure 13***),*** which are parallel to shear zones, generally injected by quartz veins and quartzo-feldspathic mobilisate. These veins are either parallel to S_2 ***(***figure 11***)***, or oblique to the foliation ***(***figure 12***)***. They are little or less deformed. This episode might have been the origin of joints and dry fractures whose striated mirrors show that they might be variable faults. This phase corresponds to a dextral strike slip fault.

C- Relationship between deformation and metamorphism.

The first deformation phase D_1 is not perceptible in the microscope. The imprint of the deformation S_1 is not seen in the studied examples due to their transposition in $S_{1\text{-}2}$ during the major deformation phase. The D_2 phase marked by the schistosity S_2, is defined in the metabasites with granular facies biotite, amphiboles and plagioclase. In the amphibolite facies, it is defined by biotite and hornblende. The mineral matrix is usually made of quartz aggregate, biotite and very deformed plagioclase. The mineralogical assemblages in this deformation phase are Cpx + Opx + Pl + Grt + Qtz + Kfs ; Qtz + Kfs + Pl + Opx + Bi + Ap + Ilm ± Cpx ; Qtz + Pl + Opx + Oxides ; Qtz + Pl + Cpx + Grt + Ru pour le faciès des granulites ***(***figure 14***)*** et à Kfs + Qtz +Pl + Cpx ± Grt ± Bi + Hbl ; Qtz + Hb + Pl ± Grt ; Qtz + Pl + Cpx + Hb ± Bi + Grt for the amphibolite facies ***(***figure 15***).***

It is noted that in the third deformation phase, a large number of studied samples show fractures of variable dimensions with identical mineral filling. We often find quartz, epidote oxides thus testifying of a low grade or retrograde metamorphism.

IV- Acknowledgment

We would like to thank Dieudonne Minyem, Théodore Mbiatso and Eric Messi Ottou, and all teacher of University of Yaounde I for his soutien inconditionnel tout au long de cette champagne.

V- REFERENCES

[1] Poidevin, J.L., ″Les ceintures de roches vertes de la République Centrafricaine (Mbomu, Bandas, Boufoyo, Bogoin). Contribution à la connaissance du Précambrien du Nord du craton du Congo″. 1991, Université Clermont Ferrand II, France, Thèse de Géologie, p. 440 + annexes.

[2] Ferré E, Dereris J, Bouchez J.L, and Lar AU, Peucat JJ. . ″The Pan-African reactivation of Eburnean and Archean provinces in Nigeria: structural and isotopic data″. Journal Geological Society London 153, 1996, pp.719–728.

[3] Feybesse J.L, Johan V, Triboulet C, Guerrot C, Mayaga-Mikolo F, Bouchot V, and Eko Ndong J. ″The West Central African belt: a model of 2.5–2.0Ga accretion and two-phase orogenic evolution″. Precambrian Research 87, 1998, pp.161–216.

[4] Almeida F.F.M, Brito Neves B.B, and Carneiro C.D.R. ″The origin and evolution of the South American Platform″. Earth Science Reviews 500, 2000, pp.77–111.

[5] Toteu S.F, Van Schmus W.R, Penaye J, and Michard A. ″New U–Pb, and Sm–Nd data from North-central Cameroon and its bearing on the pre-Pan-African history of central Africa″. Precambrian Research 108, 2001, pp.45–73.

[6] Penaye J, Toteu S.F, Tchameni R, Van Schmus W.R, Tchakounté J, Ganwa A, Minyem D, and Nsifa E N. ″The 2.1Ga West Central African Belt in Cameroon: extension and evolution″. Journal of African Earth Sciences 39, 2004, pp.159–164

[7] Nsifa E.N. ″Analyse structurale de la région du Rocher du Loup, Sud-ouest Cameroun″. 110eme Congres des Sociétés Savantes, Montpellier 4, 1985, pp. 41–52.

[8] Mvondo Ondoa J. ″Caractérisation des évènements tectoniques dans le domaine sud de la chaine panafricaine au Cameroun : styles tectoniques et géochronologie des séries de Yaoundé et de Bafia″. Université de Yaoundé I, Thèse de Doct/Ph.D de Géologie, 2009, 170p.

[9] Maurizot P, Abessolo A, Feybesse J.L, Johan V, and Lecomte P. ″Etude et prospection minière du Sud-Ouest Cameroun. Synthèse des travaux de 1978 à 1985″. 1987, BRGM Report 85 CMR 066.

[10] Toteu S.M, Van Schmus W.R, Penaye J and Nyobe JB. ″U-pb and Sm-Nd evidence for Eburnian and Pan-african high-grade metamorphism in cratonic rocks of Southern Cameroon″. Prec. Res, 67, 1994, pp.321-347.

[11] Nédélec A, Minyem D, and Barbey P. ″High P–High T anatexis of Archean tonalitic grey gneisses: the Eséka migmatites, Cameroon″. Precambrian Research 62, 1993, pp.191–205.

[12] Minyem D. ″Contribution à l'étude métamorphique et structurale du secteur Eséka-Makak (Cameroun, Département du Nyong et kéllé)″ . Université de Yaoundé I, Thèse de 3e cycle de Géologie, 1994, 166p

VI- FIGURES

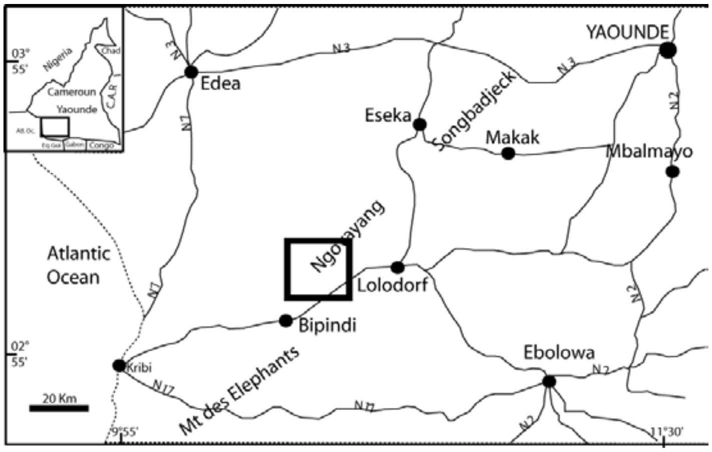


Fig. 1 Geographic situation of Ngovayang massif in Cameroon.

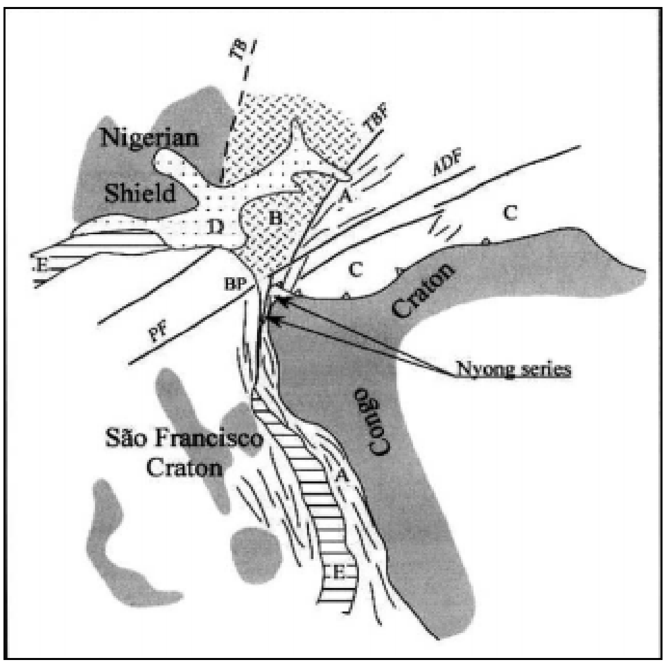


Fig. 2 Correlations *between the different Archean blocks and the western Central African belt. Western Central African belt (and its extension in Brazil) with in (A) palaeoproterozoic rocks inherited from the Archean outlined by the borders of the Congo mega Craton and (B) pan-African rocks inherited from palaeoproterozoic ; (C) napes of the Central African belt (600 Ma) ; (D) Mesozoic sediments from the Bénoué trough ; (E) Ocean. BP, Borboréma Province NE of Brazil ; PF, Pernambocu Fault ; AD, Adamaoua Fault ; TBF, Tchollīré-Banyo Fault : TB, earth limit. Modified by* ***[1], [2], [3], [4], [5], [6].***

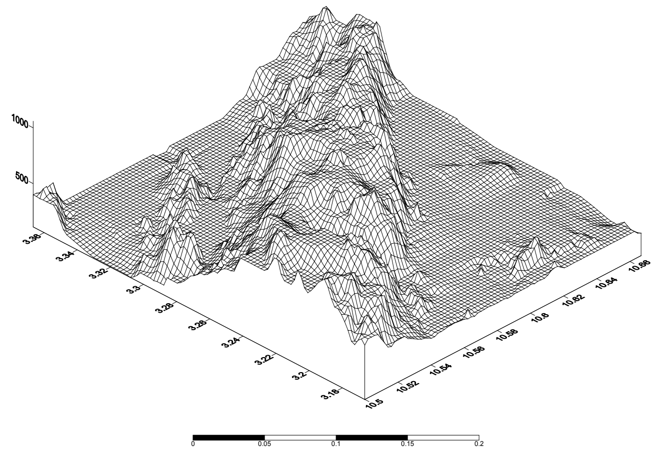


Fig. 3: A 3D Model of the study zone **.**

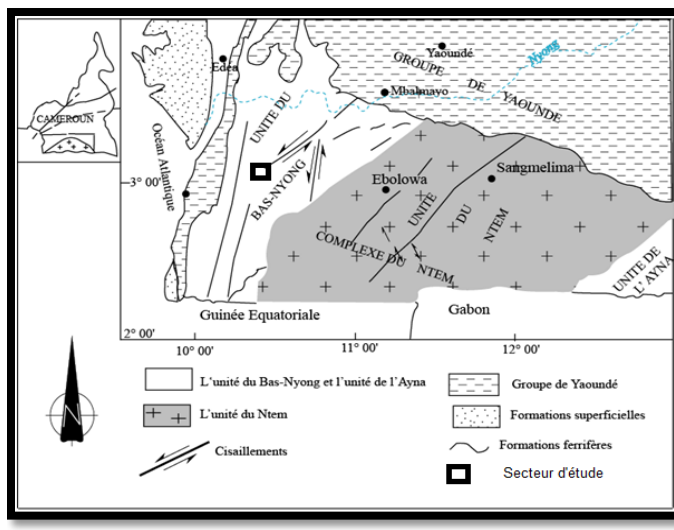


Fig 4: *Structural map of south west Cameroon* [3]**.**

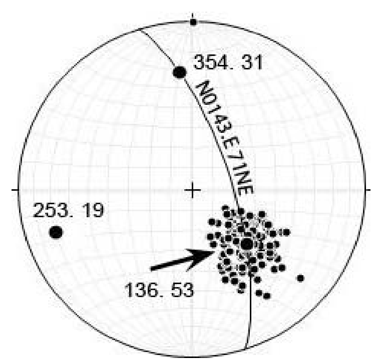


Fig 5: Poles of plans $S_{1/2}$ & P_2 (Bikalla locality) n=203

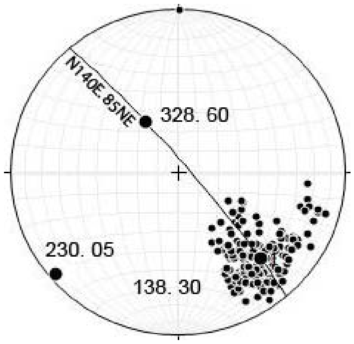


Fig 6: Poles of plans $S_{1/2}$ & P_2 (Mougue locality) n=193

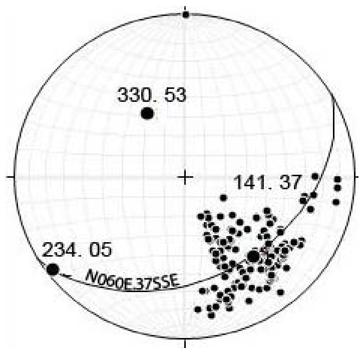


Fig. 7: Poles of plans $S_{1/2}$ & P_2 (Mbikiligui locality) n=276

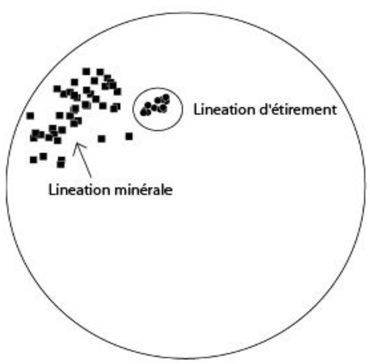


Fig. 8: lineations of study zone. n=77

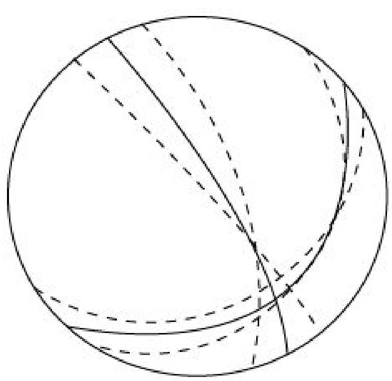


Fig. 9: folds p_2 synthesis of the study zone.

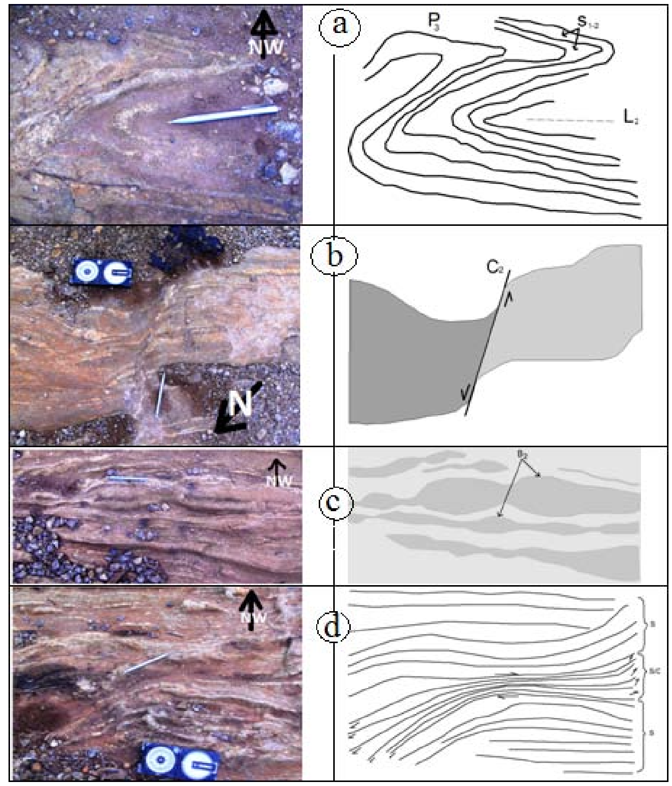


Fig. 10: Structural elements of study area

a. *Foliation undulated by P_3 folding in the Mbikiligui metabasites.*
b. *Ductile shear zone C_2 in the metabasites of Mougué locality.*
c. *Boudinaged foliation in the Bikalla environment.*
d. *Structures S/C fragilo-ductiles in one outcrop of metabasites at Molombo*

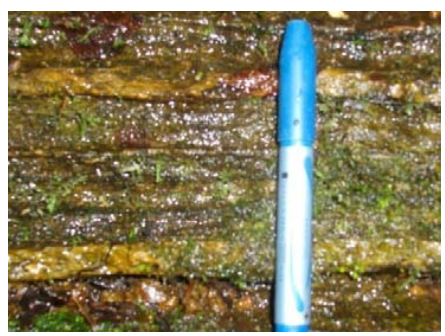


Fig. 11: veines de quartz parallèles à S1/1

Fig. 12: veine de quartz oblique à $S_{1/2}$

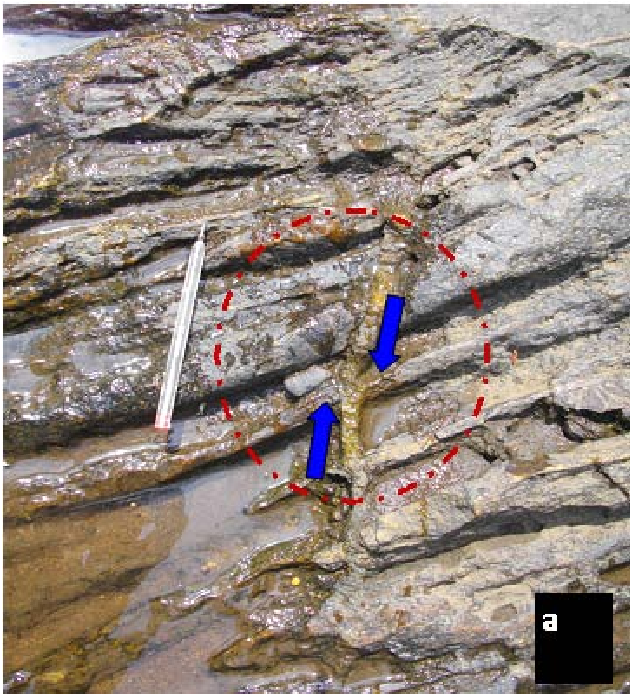
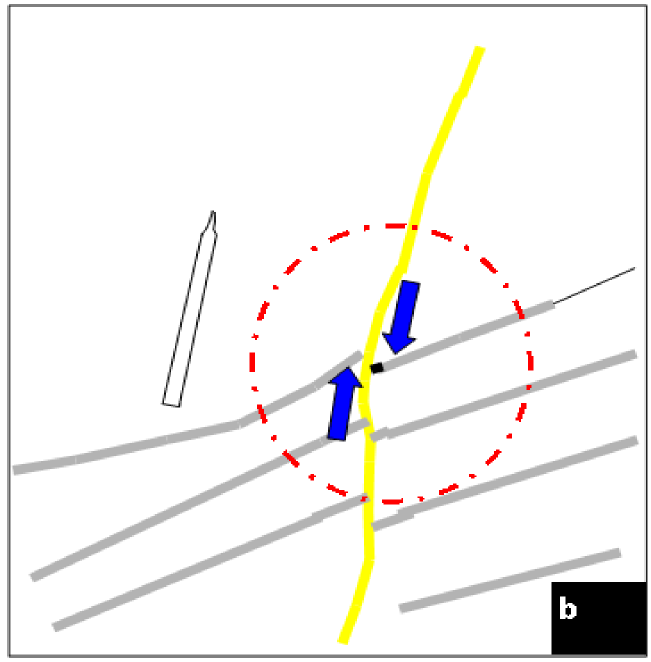


Fig. 13: Shear zone C_3 injected with quartzo-feldspathic mobilisate re-affecting the foliation in a dextral sense



Sketch of the shear zone C_3 injected with quartzo-feldspathic mobilisate re-affecting the foliation in a dextral sense.

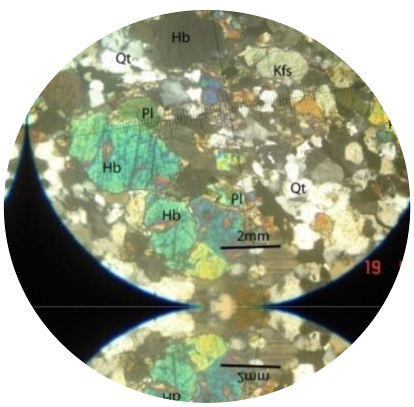


Fig. 14: métabasite à biotite (faciès des amphibolites)

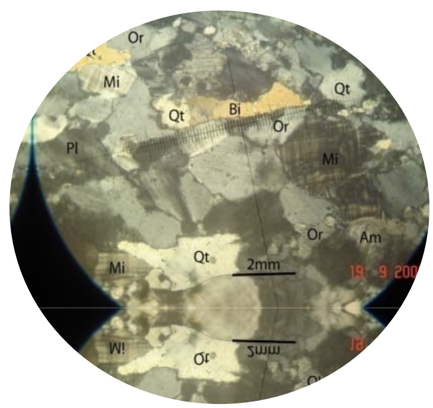


Fig. 15: métabasite à grenat (faciès des granulites).