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THE INFLUENCE OF BREAKING TECTONICS ON THE STRUCTURAL GUIDANCE OF STREAM FLOWS IN THE NORTHERN-EQUATORIAL PAN-AFRICAN CHAIN: THE CASE OF THE MAKENENE REGION

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ABSTRACT

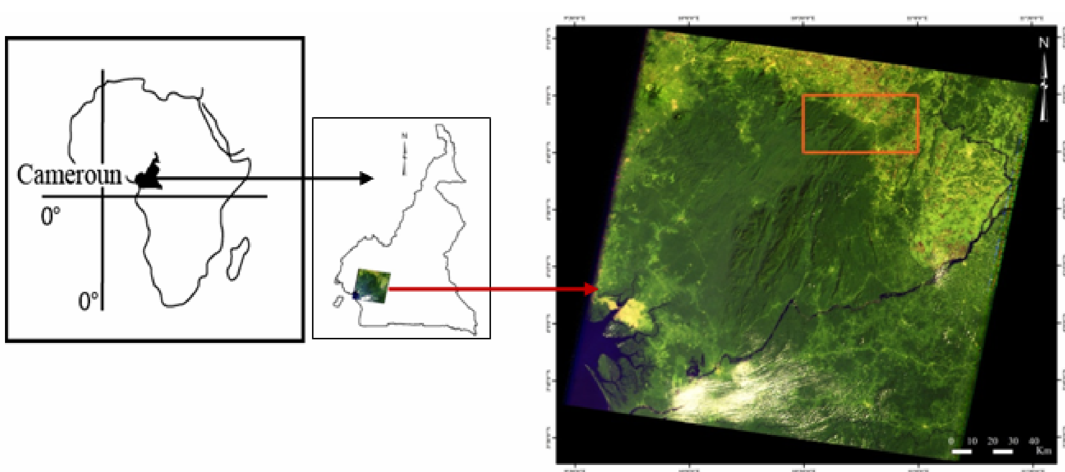
The convergence of forms and orientations between hydrographic networks, landscape and geological structures (faults, tectonic lineaments, breakthroughs) increased in mountain chains and especially in the humid tropical domain (The World Atlas) where precipitations are quite important, raises the issue of the relation and/or the influence of geological structures on nature and on hydrographical network structures. Many fieldworks on computer modelling carried out in great mountain chains (Andes Mountains) show that interactions between topographic construction, deformation, climate and erosion process can shape the structural evolution of orogens. Ganwa's works (2007) realised in the southern part of our study area show that there is a close relation between tectonic lineaments, topography and hydrography. The aim of this work is to show the influence of breaking tectonics on the guidance of stream flows. To achieve this, we will base ourselves on a comparative study of hydrography, structural analysis and landscape morphology.

Keywords: tectonics, hydrography, lineaments, orogens.

1. INTRODUCTION

The convergence between the orientation of great geological structures and that of water flows can be explained by the influence of tectonics on the guidance of the latter. This observation is even more accurate in great mountain chains as many fieldworks based on ground data and computer modelling in the Andes chains (Davis and al., 2003; Willet, 1999; Hilley *et al*., 2004; Reiners and al., 2003; Strecker *et al*., 2007), in the Himalaya (Thiede *et al*., 2004) or in New Zealand (Burbank, 2002), and in the panafrican equatorial domain (Ganwa *et al*., 2007; 1988), where the intense erosion of rocks in zones of fractures is responsible for the creation of deep valleys. Dissection modalities, notwithstanding the climate, are influenced by the nature of rocks, their disposition and the general evolution of the region. This evolution depends on tectodynamics. The morpho-climatic model is shaped according to structural landscape (Tricart J., 1968).

Our study was carried out in the Makenene region located in central-southern Cameroon, between coordinates 10° 30' and 11° 00' of longitude E and coordinates 04° 45' and 5° 00' of latitude N. This region belongs to the Bafia group (Mvondo and al., 2009) in the southern domain of Central Africa Pan-African chain (Bessoles and Trompette, 1980). In the group, Noiset (1982) defined an ancient base and a tectonic unit that overlap the Yaounde group in the South, and might represent the southern limit of the Adamawa domain in the North (Tchakounté and al., 2007). According to Bessoles and Trompette (1980), this part of the chain is of meta-volcano sedimentary origin.



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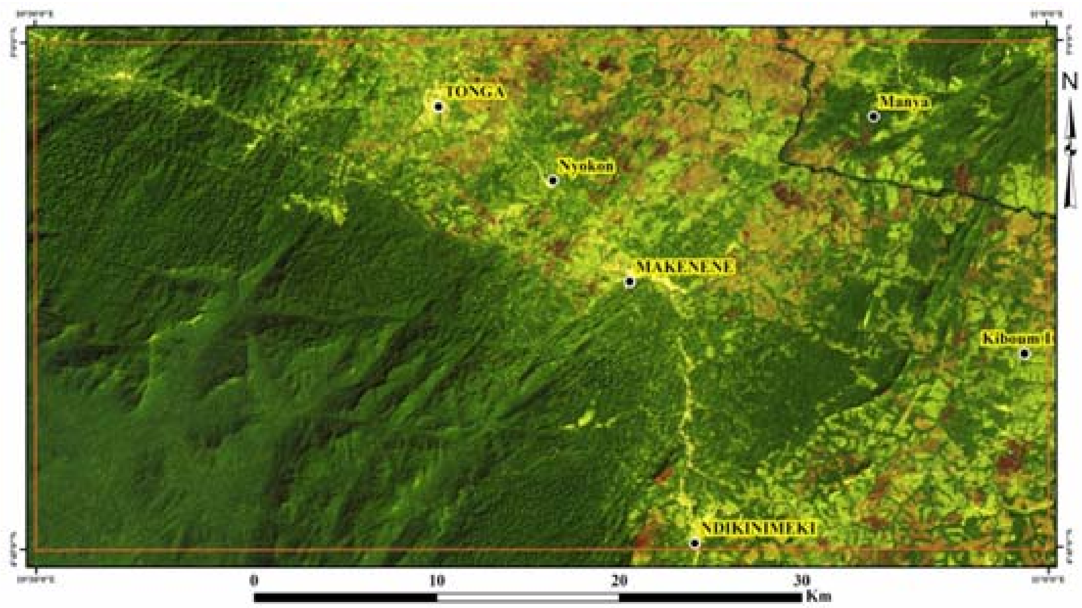

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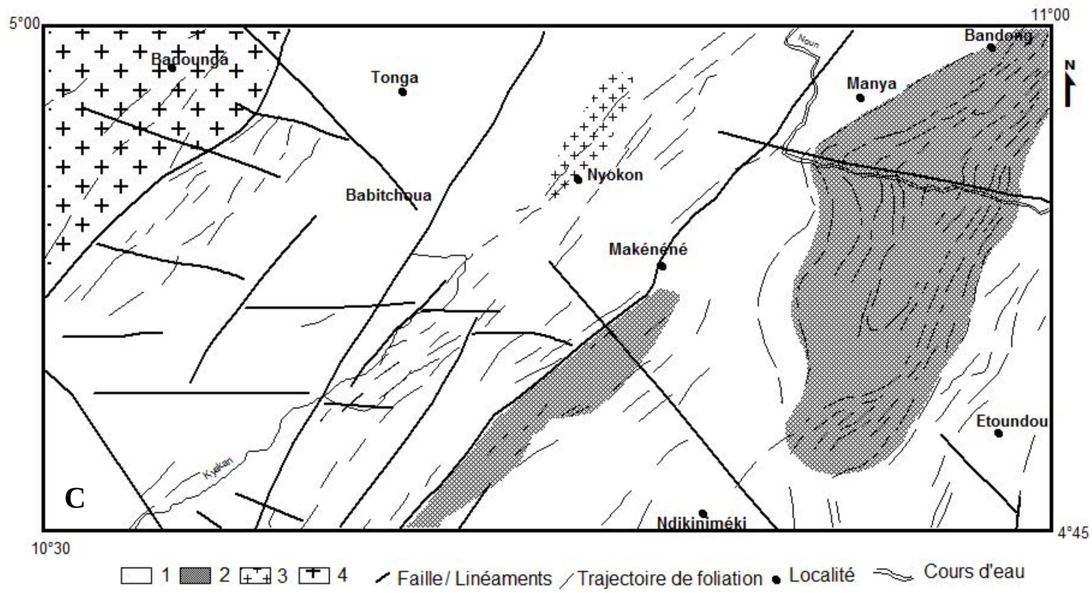

(C)

Figure-1. Localisation map of the Makenene region: A) and B) study area (Landsat image ETM+, January 5, 2007, in coloured composition RVB, 753). C) Simplified geological map of the Makenene region: 1 various gneisses; 2 quartzites; 3 charnockite; 4 porphyritic métagranites

The Bafia group is characterised by: (1) on the petrographic plan, the presence of reversed granulite assemblages of Pan-African age (Tchakounté, 1999), orthogneiss of paleo-proterozoic age (Toteu *et al*., 2001), garnet amphibolite, biotite and amphibole gneisses (Tanko Njiosseu and al., 2005a; 2005b), gneiss of various composition (garnet-biotite gneiss, garnet and amphibole gneiss, biotite and moscovite gneiss), quartzites and amphibolites (Ganwa and al., 2007). Plutonites of Pan-African age intrude into all these rocks (Nzolang and al., 2003; Tchakounté and al., 2007). On the structural plan, some authors (Ganwa *et al*., 2007) determine three phases of deformation D_1, D_2 and D_3, whereas others (Mvondo, 2009) determine four phases: D_1, D_2, D_3 and D_4. Nonetheless, for all these authors the last phase is a breaking one while the preceding ones are ductile. This region is characterised by a peculiar hydrography and orography dominated by successive hills and a hydrographical network of angular confluence (Figure-3). A structural geomorphologic study whose aim is the

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description and the explanation of the convergence between the tectonic structure and the guidance of water flows is combined to the interpretation of satellite images, a geomorphological analysis and an analysis of ground data in order to assess the inter-dependent relation that might exist between the morphology and the structural geology in the region of Makenene.

2. MATERIALS AND METHODS

During our research, we used classical tools of field work. The recognisable structural elements (direction, dip and plunge) in the field have been described, measured with the compass (TOPOCHAIX) and located using a Magellan 13 GPS. The various kinds of rocks were identified with the eye in the field and with a microscope after the study of thin blades. The different structural and hydrographical lineaments were identified after the study and interpretation of topographic maps and satellite images. Field data underwent a statistical study and were analysed in a laboratory with Stereo Net software for the drawing of faults and water directions density diagrams.

3. GEOLOGICAL SETTING

The Makenene region belongs to the southern domain of the north-equatorial Pan-African chain of Cameroon (Nzenti J. P., 1987. (Figure-1)). Several works of geology (Noumben Tchakounte *et al*., 2007; Mvondo Ondoua J., 2009; Ganwa A. A., 2007; Ganwa A. A. *et al*., 1998; 2003., 2001; Weecksteen C., 1957) carried out in this region and its vicinity show that it is made up of micaceous quartzites, iron quartzites, amphibolite shoals interstratified with various gneiss more or less migmatites: biotite amphibolite gneiss, biotite garnet gneiss, granulites and biotite plagioclase gneiss, on the petrographic plan. These rocks are combined to NNE-SSW oriented metaplutonites of Pan-African age.

On the structural plan, one can identify at least three phases of deformation. The first phase is characterised by a transcurent tectonic with big shears in the west of Makenene. The second phase is characterised by a supple tectonic recognisable by its regional folds in the east of Makenene. The last phase is a breaking one with faults and regional lineaments of various directions visible on satellite images.

4. RESULTS

4.1. Morphological units

Our area of study is a rectangle of about 1540 km^2 located between coordinates 10° 30' and 11° 00' of longitude E and 4° 45' and 5° 00' of latitude N. This area is characterised by a sequence of terraced shelves, generally cut with deep valleys in which the main rivers flow (Noun, Nde, Manoui, Makenene, Molo). This setting led to the division of this area into five morphological units: a morphological unit of over 900m high, a morphological unit of 500 to 700m high, a morphological unit of 300 to 500m high and a morphological unit of less than 300m (Figure-2).

a) **The morphological unit of over 900m high** is located in the North-West of Makenene. It is a homogeneous unit subdivided into two groups separated by a valley of medium altitude (800m). In the South-West of Makenene, this unit is characterised by a series of small lined hills oriented according to NNE-SSW to NE-SW direction, in parallel with foliation patterns (Figure-1). On the petrographic plan, this unit is the uncovered area of granite rocks (Tonga-badounga-Babitchoua) and quartzite (micaceous quartzite and iron quartzite) which occupy the highest parts of the hills (South-East and South-West of Makenene).

b) **The morphological unit of 700 to 900m high:** this unit is quite wide given our area of research. It goes from the south to the west of Makenene. In the East, it is represented by two shelves of small dimension oriented NE-SW to NNE-SSW. On the petrographic plan, this unit is made up of quartzite in the East whereas gneiss and migmatite are found in the South and the West. The transition with the unit of 500 to 700m is smooth (Figure-2B: D-D and E-E fault).

c) **The morphological unit of 500 to 700m high:** It is the most represented unit in this area. It occupies the whole eastern part of the studied domain. On the petrographic plan, one can find various gneiss (garnet + biotite gneiss, amphibole + biotite gneiss). This somewhat extended domain on the geographic plan is characterised by narrow and deep valleys in which main rivers such as Noun, Manoui, Nde and Molo flow (Figure-3).

d) **The morphological unit of 300 to 500m high** is the smallest one. Made up of deep, narrow and abrupt valleys as proves the changes on the topographic plan (coted points in the South-West of the area, topographic profile of A-A cut, Figures 2(A) and 2(B)), this unit is a transition zone between the former one and the morphological unit of less than 300m high.

e) **The morphological unit of less than 300m** is quite a large domain that extends to the West and the South by the Makombe plain whose altitude is equals to or inferior to 300m.

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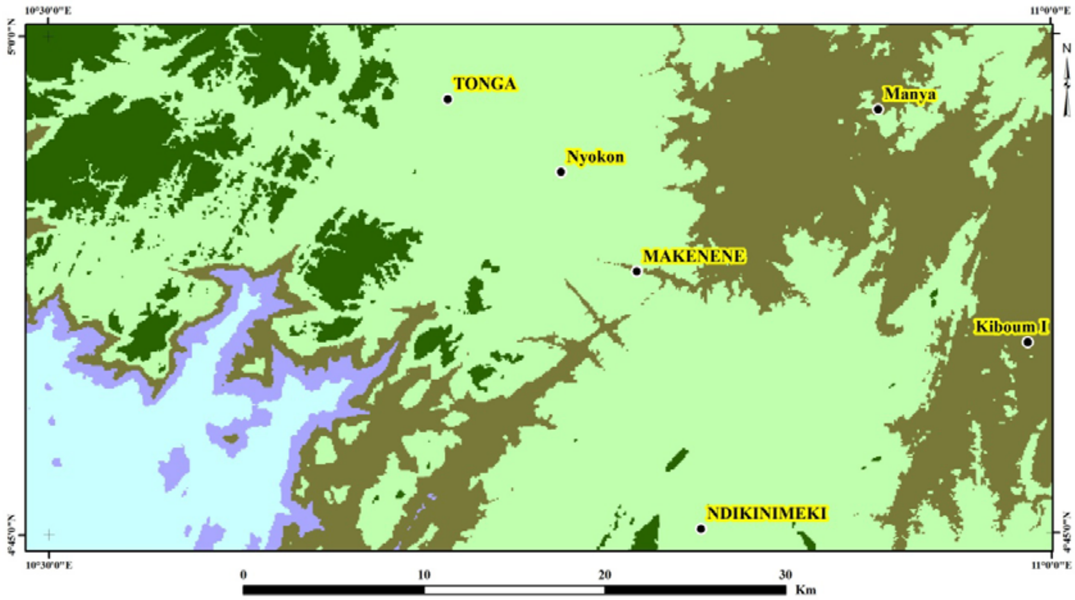

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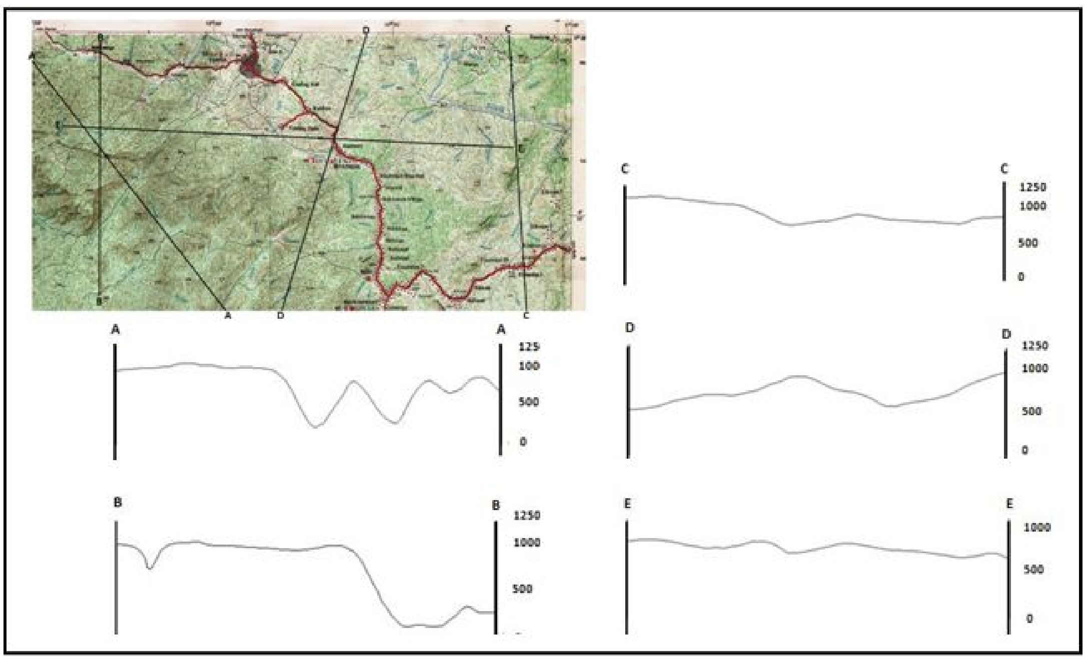

(B)

Figure-2. A) Morphological unit map of the Makenene region. There are five topographic levels that show the landscape towering of the region; B) topographic map on the scale of 1/200 000 and topographic profiles of the Makenene region. A-A and B-B cuts convey the presence of deep valleys and the sudden slope break between the domains of an altitude > 900m in the NW and height < 500m in the SW of the area (SRTM 90m classified image).

4.2. Hydrographic network

The Noun in the North and the Makombe in the South are the main collectors of rivers and streams in the Makenene region. These collectors belong to the Mbam river basin in the North and the East, and to the Sanaga water basin in the SW (Figure-3). It is a dendritic network, with fishbone patterns, in which branches making sub-perpendicular (the Noun basin in the North) or sharp angles with main collectors meet the rectilinear main streams. It is a dense network characterised by the presence of permanent streams. Some, important ones, have more than 7 streams (Nde, Molo, Kyakan, Manoui,

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Makam, Makenene, Mbome). The most important streams are generally straight and are oriented into two main directions: a NNE-SSW to NE-SW direction and an ESE-WNW direction. The waters' linear portion density diagram (Figure-5a) confirms these orientations.

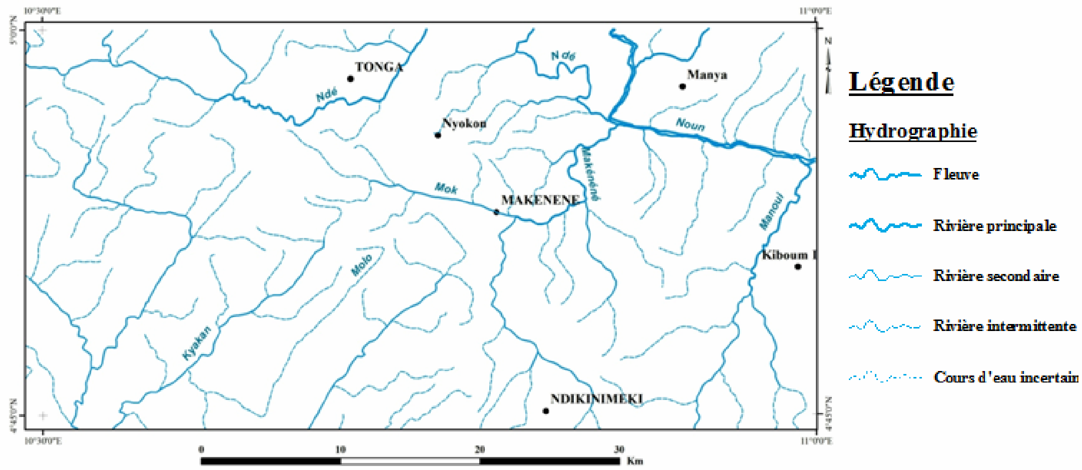

Figure-3. Hydrographical network of the Makenene region. In the North, the Mbam basin and in the South-West, the Sanaga basin (hydrographic network taken from the interactive forestry atlas of Cameroon V2).

4.3. Structural study

The presented structural study results come from the compilation and the correlation of field data (Figure-4a), and satellite image analysis (Figure-4b). Our study reveals that the Makenene region is characterised by various types of tectonic that correspond to several phases of deformation. A synthetic approach (Figure-5) of this analysis reveals three phases of deformation: a D_1 phase, a D_2 phase (ductile), and a final breaking phase D_3. The first two phases are recognisable by S_1 and S_2 foliations which carry L_1 and L_2 lineations. P_1 and P_2 folds as well as C_1 and C_2 shears are also present in the field. The West and the Centre of Makenene (Badounga, Tonga, Makenene) are the domain of transcurent tectonic characterised by big vertical strike-slips. The South and the East of Makenene have a folded tectonic. The main tectonic structures (foliations, folds, shears) have various directions and illustrate a supple tectonic characterised by folds of regional scale (Figure-5). The third phase of deformation, mainly a breaking one, is marked by faults, fractures and lineaments of various height observed in the field and inferred from the interpretation of satellite images (Figures 4A and 4B). The faults' orientation leads us to two main directions: a NNE-SSW to NE-SW direction and an E-W to ESE-WNW direction (Figure-5).

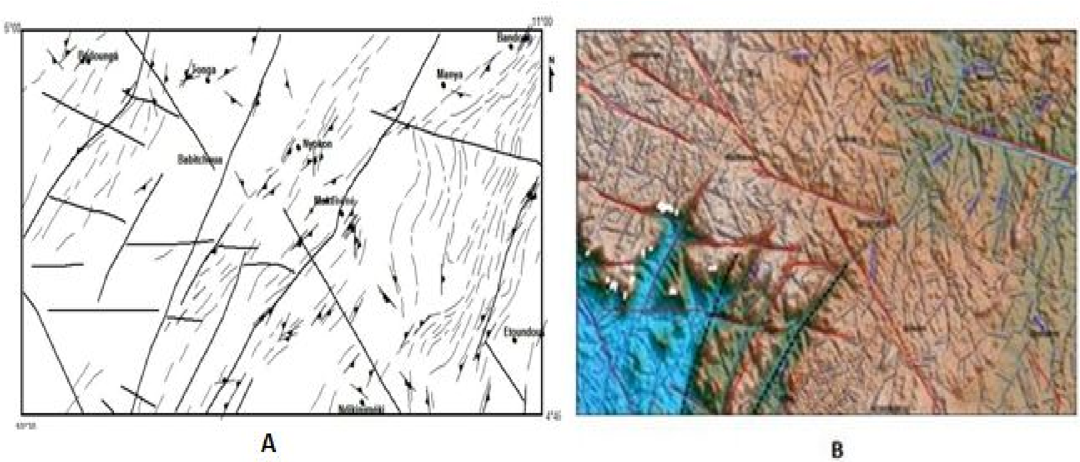

Figure-4. Structural map of synthetic field data and satellite images interpretation comprising faults, lineaments, foliations and foliations paths: (A) confirmed observation in the field and (B) satellite image data (shaded SRTM image).

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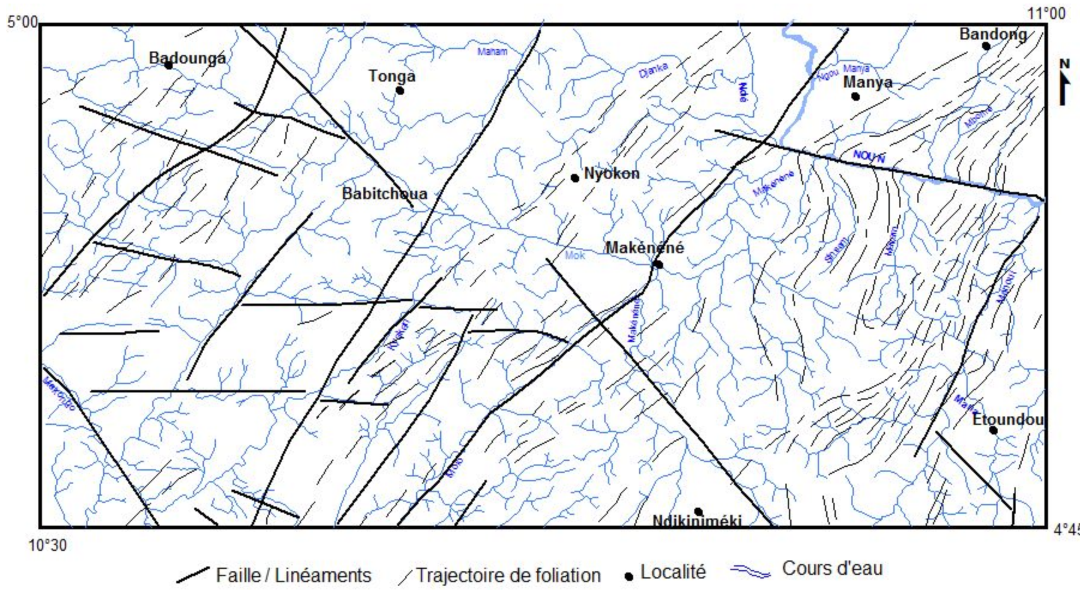

Figure-5. Overlaying of structural and hydrographic maps of the Makenene region. Faults and foliation paths were determined from field data and satellite image interpretation. The hydrographical network was drawed using the topographic map and the satellite image interpretation. One can notice the convergence between the faults and regional lineaments direction, and waters paths.

5. DISCUSSIONS AND CONCLUSIONS

The Makenene region is an overlapping zone between the Sanaga basin in the South and the Mbam basin in the North. Our area of study is a large shelf with several floors, cut by deep valleys whose highest and shortest points are respectively 1114m high in the NW and 134m high in the far SW of Makenene. The dense and permanent hydrographical network is a dendritic one, with fishbone patterns. There are two main collectors: in the North and the East the Noun (an important stream of more than 7), tributary of the Mbam in which it throws itself in the East of Makenene and the Makombe (tributary of the Sanaga) in the South-West. The geometry of the Noun's flow is a sequence of river branches which take turn in a right angle. These arms go into two directions: a NNE-SSW to NE-SW direction and an E-W to ESE- WNW direction. This orientation is the same with that of the whole streams in the region.

The structural interpretation of field data and that of satellite images enable us to identify lineaments, faults, foliation paths, folds and shears as the major structures that affect the Pan-African groups of the Makenene region. Just as the streams in this region, these structures have two main directions: NNE-SSW to NE-SW and E-W to ESE-WNW.

Overlaying the network hydrographic and structural maps (Figure-5) shows a clear convergence between the streams and the faults directions. The major examples are taken after observing the behaviours of some rivers: Noun, Molo, Kyakan, Mok and Manoui. In fact, the rivers' patterns are parallel to those of the faults and perfectly superposable following the NNE-SSW to NE-SW (Noun, Manoui, Kyakan, Molo) and E-W to ESE-WNW (Mok, Noun) directions. As for foliation paths, only a category of rivers (NNE-SSW to NE-SW) are parallel to them. The second category is secant to these paths that are those of faults and lineaments of ESE-WNW direction.

Studies carried out in the East (Dumont J. F., 1986) and the South (Moussango A. P., 2003; 2001; Moussango A. P., not yet published; Ganwa A. A., 2007) of our area of study show that fractures follow two main directions: a Pan-African direction NNE-SSW to NE-SW (Moussango, to be published) and an apto-albian direction E-W and N-S to S-E, that correspond to the opening of the southern atlantic (Njiké Ngaha, 1984; Kossoni, 1992; Moussango, 2001; 2003). If for Moussango (to be published) these fractures guide most of the streams in the region, for Ganwa, rivers and springs systematically follow foliation or fracture paths.

The Makenene region is a towering shelf with very deep valleys. The detrital water system in this area overlaps between the Sanaga and the Mbam basins. This area has been affected by three phases of deformation: two of ductile deformation and one of ultimate fragile deformation made up of faults and fractures oriented in two directions (a NNE-SSW to NE-SW direction and an ESE- WNW to SE-NW direction), following Moussango (2001; 2003), Ganwa (2007) and Kossoni (1992) research results. The superimposition of density maps and diagrams of tectonic structures with hydrographic maps (Figure-6) show a clear convergence between the forms and orientations of water patterns as well as tectonic direction at the scale of the region. This proves that tectonics has a great influence on the guidance of stream flows in this part of the Pan-African domain.

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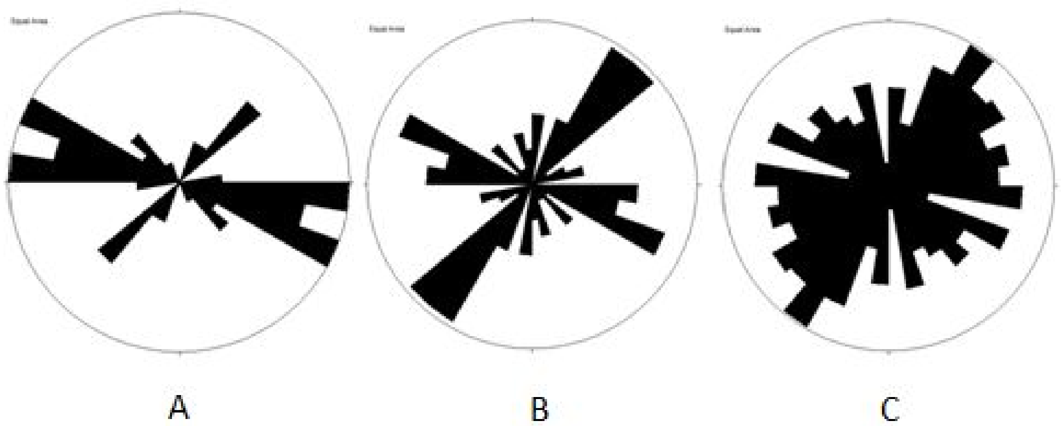

Figure-6. Density diagram of the orientation of tectonic structures and streams in the Makenene region. A) Linear parts of streams. B) Faults and fractures measured in the field and inferred from the Interpretation of satellite images. C) Water directions.

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