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Research Article

ANALYSIS OF DEFORMATION IN THE MIDDLE KIBARIAN OF THE SOUTH-EAST OF KAMISIMBI (SOUTH KIVU; DR CONGO)

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Abstract

The present work aims to strengthen the understanding and updating of the geological history of the Kibarian orogeny in Kivu, in the East of the Democratic Republic of Congo through the study area, South-East of Kamisimbi (Middle Kibarian) in Walungu territory. In other words, it involves characterizing all tectonic phases, both continuous and discontinuous deformations. After a detailed macroscopic description of the lithological groups identified in the field, the structural analysis was carried out at the macroscopic and mesoscopic scale. The results obtained show that the South-East of Kamisimbi is made up of three lithological groups: sedimentary (sandstone, conglomerate), metamorphic (shale and quartzite) and volcanic (basalt, trachyte). Structurally, the South-East of Kamisimbi presents a tectonic evolution marked by three (03) phases of deformation (D1, D1' and D2). Phases D1 and D1' (shear phase) folded, then sheared the South-East of Kamisimbi giving structures with an axis from WNW-ESE or E-W to NW-SE and sometimes N-S. The D1 deformation phase, essentially ductile, includes an F1 foliation, an S1 schistosity and P1 microfolds in shales and sandstone shales with low to medium dips (10° – 47°). The majority of P1 microfolds identified on the ground in the South-East of Kamisimbi, oriented N087°E to NW84°E are more or less parallel to the major folds (N085°E; N090°E and N100°E) constructed from S0 to which they are linked. Others, on the other hand, oriented N046°E have highly dispersed axes and would therefore have a sedimentary origin (Slump), non-tectonic. The deformation phase D2, both posterior and intersecting with the first two D1 and D1', is the most marked in the study area. It is identified in almost all rocks and results in fractures, whether sustained or not, mainly D2 joints, J2 joints, F2 veins and veins. The orientations of the principal stresses which generated the brittle deformations were also determined from the dynamic interpretation of the fracturing fed or not on Wulff canvas. Thus, we have the major principal stress(N150°E/10°SSE), the intermediate principal stress(N170°E/10°SSE), the minor principal stress (N078°E/08°ENE) and the maximum tangential stress(N058°E/45°NE) for the joints and the major principal stress(N014°E/68SSW), the intermediate principal stress(N047°E/010°NE), the minor principal stress(N134°E/11NW) and the maximum tangential stress (N124°E/53°WNW) for the veins. On a regional scale, the first phase D1 and the second D1' defined in the South-East of Kamisimbi would correspond respectively to phases D2 and D2' of Kibarian deformation where the structures are oriented NW-SE; WNW-ESE to E-W.

Key words: Deformation, Kibarian Orogeny, lithology, Kamisimbi, Democratic Republic of Congo.

INTRODUCTION

Most of the geological history of the African continent is based on the Precambrian basement. This base is made up of several cratons which each correspond to continental crusts stabilized around 2.5 Ga and separated by more or less wide zones called orogenic belts (Klerkx, 1985; Feybesse *et al.,* 1998). If the African continent was only slightly affected by the Hercynian orogeny (400 Ma) on its northern (Morocco), western (Senegal-Mauritania) and southern (Cape Town) margins, the major orogenies which marked Africa are the Liberian (2.8Ga), Eburnean (2.1Ga), Kibarian (1.5Ga) and Pan-African (600Ma) orogenies, the last being the most widespread (Feybesse *et al.,* 1987; Feybesse *et al.,* 1998; Kouankap, 2011). Located in central Africa, the Democratic Republic of Congo is found within these geological groups. Its eastern part is dominated by the Kibarian orogeny. Indeed, the Kibarian chain (Mesoproterozoic) extends from southern Katanga to Great Kivu (Maniema, North and South Kivu) in a North-East, South-West direction before extending into Rwanda, Burundi and Uganda (Villeneuve, 1976; Ledent, 1978; Villeneuve, 1980; Kampunzu *et al.,* 1986; Kokonyangi *et al.,* 2006; Villeneuve *et al.,* 2019; Villeneuve *et al.,* 2022).

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The Kibarian chain is interpreted either as a collisional orogenic chain having experienced the complete Wilson cycle, or as an intracratonic orogenic chain having different consecutive periods of extension and compression, or marked by an intraplate tectono-magmatic event in 1375 Main an extensive context (Klerkx *et al.,* 1984; Kampunzu *et al.,* 1986; Klerkx *et al.,* 1987; Rumvegeri *et al.,* 2004; Kokonyangi *et al.,* 2004; Koko-nyangi *et al.,* 2006). In the Democratic Republic of Congo, the Precambrian terrains belonging to the Kibarian orogeny are subdivided into three groups: the lower, middle and upper Kibarian (Villeneuve, 1977; Rumvegeri, 1987; Villeneuve *et al.,* 2004). The geological formations of the South-East of Kamisimbi, study area, part of the Nyangezi group in the Precambrian of southern Lake Kivu, belong to the Middle Kibarian (Villeneuve, 1977; Rumvegeri, 1984). If the other segments of the Kibarian chain (Katanga, Burundi, Rwanda, etc.), are well defined, the segment of Kivu-Maniema in general and South Kivu in particular is not yet sufficiently defined, although covered by certain geological works (Villeneuve, 1977; Rumvegeri, 1985; Rumvegeri, 1987; Villeneuve and Chorowicz, 2004; Mugisho *et al.,* 2014). This is the case of the Precambrian of the south of Lake Kivu: stratigraphic, petrographic and tec-tonic study (Villeneuve, 1977), of the Precambrian of the West of Lake Kivu and its place in the geodynamic evolution of Africa central and eastern (Rumvegeri, 1987), the characterization of deformation in the Upper Kibarian (Mugisho *et al.,* 2014). In addition, most of this work was carried out on reduced scales which did not allow certain details to be highlighted on the areas covered. For example, apart from the general geological map of Zaire (1974), there is only one synthetic cartographic document: the 1/500,000 geological map of Eastern Kivu (Boutakoff, 1939; Leper-sonne, 1974). It is in this context that this present work finds its place and therefore its contribution in the analysis of deformation in the Middle Kibarian of the South-East of Kamisimbi in order to better understand it and update its geological history.

Regional geological framework

In the Precambrian of South Lake Kivu, the formations belonging to the Kibarian orogeny are divided into three large lithostratigraphic units (Villeneuve, 1977; Rumvegeri, 1984; Villeneuve, 2013). This is from top to bottom:

- Itombwe formations (upper Kibarian);
- From the Nyangezi group (Middle Kibarian);
- From the Bugarama group (lower Kibarian).

These three lithostratigraphic units are discordant with each other and present large lithological, sedimentological and tectonic differences (Villeneuve, 2013). Comparisons and correlations of these three units have been made with the subdivisions of neighboring countries in Rwanda and Burundi into Burundian and Ruzizien (Villeneuve, 1977; Rumvegeri, 1987). These comparisons showed that the Nyangezi group has all the characteristics of Burundian (between 1600 and 1000 Ma), while the Bugarama group can be considered either as lower Burundian or as Ruzizian (less than 1600 Ma). Under these conditions, the Itombwe formations are post-Burundi (greater than 1000 Ma). As for the Ruzizi granite, a more in-depth study will perhaps make it possible to find a regional equivalent (Villeneuve, 2013). The Middle Kibarian, which includes the South-East of Kamisimbi, corresponds to the Nyangezi group. In this group, stratification is clearly visible at all scales while the effects of metamorphism are not always discernible to the naked eye (Villeneuve, 1977). This group begins with powerful quartzite levels (Bangwe formation) followed by a mainly schistose and quartzophylladic group (Mukobio formation). It ends with quartzites and quartzophyllades, sometimes conglomeratic, very rich in Magnetite and quartzite crystals and quartzophyllades, sometimes conglomeratic, very rich in Magnetite and oligist crystals (Mughera formation) (Villeneuve, 1977).

Structurally, micro and mesotectonic research has shown the existence of four folding phases (Villeneuve, 2013): D1, D2, D2' and D3. Phase D1 folded the Bugarama group but was not observed in the Nyangezi group (Villeneuve, 1977; 2013). Phases D2 and D2' (shear phase) folded, then sheared, both the Nyangezi and Bugarama groups, giving NW-SE or WNW-ESE to E-W axis structures. In fact, the orientations are variable, some P2 microfolds can have a SW-NE direction, but it is the NW-SE orientation which is statistically the most frequent (Villeneuve, 1977). As for phase D3, it is found in all units but is the only one present in the Itombwe formations (Villeneuve, 2013; Mugisho *et al.,* 2014). It generated folds in a N-S direction, asymmetrical and sometimes shifted towards the west and sometimes towards the east. Phase D1, synchistose (flow schistosity) gave isoclinal microfolds at the curved hinge. The D2 phase, also synschistous, gave micro and megafolds of isoclinal style and thrown towards the SW. This phase caused microshears as well as significant flaking. Phase D3, which is still synschistous (flow and fracture schistosity), is the origin of the N-S axis micro and megafolds, of a similar type, open, symmetrical and with a rounded hinge. All these flexible deformations are followed by brittle deformations, some of which are linked to the African rift (Rumvegeri, 1991; Villeneuve, 2013). In the Nyangezi group, the metamorphism is two-phase and epizonal. Recrystallizations of muscovite, sericite and often biotite are observed. In the Bugarama group, it is three-phase and mesozonal, with the appearance of biotite, garnet and staurolite. It is single-phase in the Itombwe formations where the presence of muscovite and sericite indicates epizonal type metamorphism (Villeneuve, 2013). The number of tectonic phases as well as the various degrees of metamorphism varying from one unit to another highlight the structural differences between them (Villeneuve, 2013).

MATERIALS AND METHODS

Field work

The field work consisted of the general reconnaissance of the study area, the location of accessible and more suitable outcrop sites (mountains, rivers, escarpments and roads), the geological description and geometric identification, respectively lithological and structural characters as they occur. In the field, the rocks were described first at the outcrop scale and then at the sample scale.

- At the scale of the outcrop, the type of outcrops (benches, blocks, flows) is identified according to the estimation of the size and extension of the slab in the N-S and E-W directions and the diameter of the block. Structural elements such as veins, joints, shears and mesoscopic folds were also examined at this scale.
- At the sample scale, the aim was to determine the nature of the rock (recognition and description of minerals), the petrographic types and the chronology of the structural elements (foliation, schistosity and folds).

The equipment used for localization includes a camera and a Garmin brand GPS receiver device. A Sylva Ranger 15T brand compass equipped with a clinometer was used for structural measurements. In order to properly describe the rock, the geologist's hammer was used to break the rock following planes of weakness and observe the freshest zone of the latter.

Data processing

The processing of essentially structural data collected in the field (structural elements) consists of the projection of their attitudes into the lower hemisphere of Wulf's canvas using stereonet software as well as the processing of these attitudes by certain computer software (Dips, ArcGIS10).

Results

Lithological inventory

In the study area, field work and macroscopic petrographic studies reveal the presence of three lithological groups, essentially sedimentary, metamorphic and volcanic, respectively made up of conglomerates and sandstones, schists and quartzites, basalts and trachytes. The lithological inventory was carried out on three main sites with more favorable outcrops, chosen for their easy accessibility. These are Mounts Nyabalenga, Misisi and Nanshembe. Road trenches were also combined for this purpose. Sandstones, shales and quartzites crop out in the form of benches on all three sites. But, in places, sandstones crop out in the form of blocks, as do conglomerates. The Phanerozoic formations: basalts and trachytes, are exposed respectively in the form of flows from compact basaltic prisms and in the form of massive flows reworked on the road cuts leading towards Mount Nyabalenga (Fig. 2). To the South-East of Kamisimbi, study area, sandstones constitute a major formation, representing approximately 60% of the outcrops, conglomerates constitute a minor formation (approximately 3% of the outcrops). On Mount Nyabalenga, the quartzites present in places clear contacts parallel to the general appearance of the layers with the schists (figure 1a). At the banks of the Karhendere River, we can observe a network of fractures on the shale (figure 1b).

Figure 1. Clear contact between quartzite and schist on Mount Nyabalenga (1a) and network of multidirectional fractures on the left bank of the Karhendere River (figure 1b)

Figure 2. Outcrop of basalts.

Structural analysis

The three lithological groups (sedimentary, metamorphic and volcanic) of the study area are affected by ductile (schistosity/foliation, folds) and fragile (fractures and shears) structures of various attitudes. Using the parallelism of the structural elements between them and the principle of overlap, a relative chronology was established. The geometric and chronological analysis of these structural elements thus makes it possible to group them into three (03) main deformation phases designated D1, D1' and D2. Each of these deformation phases is characterized by structures visible on the ground. In this part, the study of the structural elements will be done according to these different phases of deformation.

Deformation phase D1: The first phase of D1 deformation is essentially ductile in the South-East of Kamisimbi. Structural elements associated with this phase are recognizable in shales, sandstones and sandstones. South-east of Kamisimbi, this phase of deformation is characterized by foliation F1, schistosity S1 and folds P1.

Foliation F1 / Schistosity S1: In the study area, schistosity S1 is observed mainly in shales and sandstone shales. Outcrops allowing good observation of this structure are found at Mount Nyabalenga where the shales are in clear contact with the quartzites (Fig. 1a) and at Mount Nanshembe (Fig. 3). The foliation F1 is marked by an alternation of light beds of quartzo-feldspathic composition with thicknesses varying between 2 and 5 mm and dark beds composed of ferromagnesian minerals with millimeter thicknesses. This is a "compositional bedding" type foliation. The schistosity S1 is marked by the preferential orientation of the minerals parallel to the foliation F1. In both shales and sandstone shales, the direction of schistosity S1 varies between N266°E and N288°E and dips towards the NNE.

Figure 3: Planes of Schistosities S1 observed on the shale at Mount Nyabalenga.

Folds P1: The P1 folds were observed on all the formations in the study area. They are of the intrafolial or synschistous type. In total, three decimetric to centimeter-sized microfolds, more or less symmetrical, were observed in the field. These are straight folds in the vertical axial plane. They result from the folding of the S1 developed during the D1 deformation phase. These three microfolds observed on the ground have axial planes whose directions are respectively N087°E, NW84°E and N046°E as well as axes which plunge respectively towards the East for the first two and towards the NW for the third. Furthermore, three major folds constructed from the stratification planes on the Wulff stereographic canvas (Fig. 4 and 5) and on the geological map (Fig. 18) show the following orientations:

- Syncline 1: oriented N100°E with a dip of 86°SSW, whose axis plunging towards the ESE is oriented N100°E;
- Anticline: oriented N090°E with a dip of 86°S, whose axis plunging towards the east is oriented N090°E;
- Syncline 2: is oriented N085°E with a dip of 78°SSE. Its axis is oriented N085°E with an extension of 06°ENE.

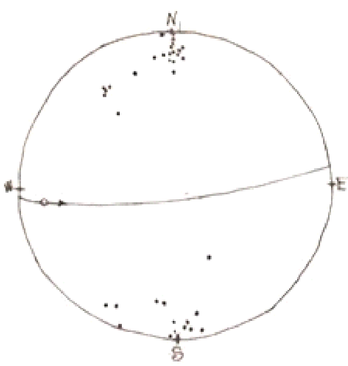

Figure 4. Determination of Syncline 1 from So stratification planes on Wulff stereographic canvas

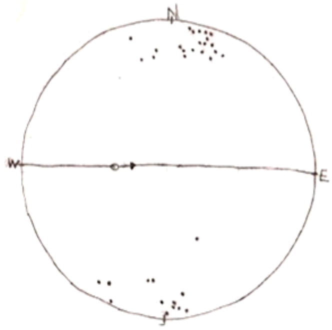

Figure 5. Determination of the anticline from So stratification planes on Wulff stereographic canvas.

Among the microfolds observed in the field, only two oriented N087°E and NW84°E are more or less parallel to the major folds to which they are linked. The microfold oriented N046°E would have a sedimentary origin (slump), non-tectonic, that is to say syn-sedimentation because its axis is highly dispersed.

Deformation phase D1': This phase of deformation is marked by planar structures, notably the C1' Shears. The C1' shears are materialized by the sectioning of the quartz veins and are observed mainly in the sandstones on Mount Nyabalenga (Fig. 6). The average orientation of the shear planes varies from N315°E with a dip of 65°NE to N180E and 50°W dip. These C1' shear planes have dextral and sinistral polarity (Fig. 6). These directions of movement are revealed by the presence of hooks in the sandstones, thus indicating a dextral and sinistral kinematics of the C1' shear planes oriented respectively NW-SE and N-S.

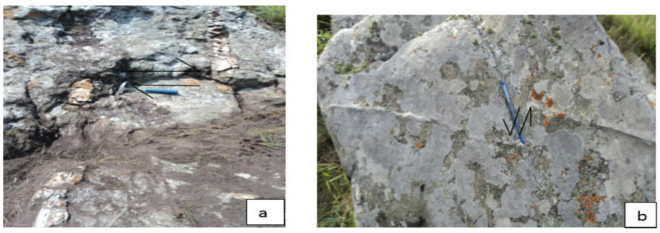

Figure 6. Dextral (a) and sinistral (b) offsets.

Deformation phase D2: The D2 deformation phase is the most marked in the study area, because it is identified in almost all sedimentary and metamorphic rocks. This phase of deformation results in planes of discontinuity. These are mainly D2 joints, J2 joints, F2 veins and veins.

Joints and joints: In the study area, joints and diaclase affect quartzites and sandstones more particularly than other formations (Fig. 7). The multidirectional networks of joints and diaclase affecting the quartzites and sandstones to the South-East of Kamisimbi are preferentially oriented SSW – NNE, with medium (40 to 58°) to steep (63 to 72°) dips inclined towards the West (Fig. 8). For all the joints and joints in the sector studied, two poles (P1 and P2) oriented respectively N154°E/40°SW and N175°E/50°E are determined (Fig. 9). For the statistical distribution of joints and joints, the maximum concentration of the poles is 11.1% (Fig. 10). However, the frequency rosette highlights the existence of four major families of joints (Fig. 11):

- a management family N 350° to 360°E;
- a family of direction N 00° to 10°E;
- a family of direction N 10° to 20°E;
- a family of direction N 20° to 30°E;

Furthermore, by reporting the results of the measurements of each joint on the stereographic canvas, we determine the orientation of the constraint vectors having generated the discontinuity (Fig. 12). Thus, we have the major principal stress (N150°E/10°SSE), the intermediate principal stress (N170°E/10°SSE) and the minor principal stress (N078°E/08°ENE). The maximum tangential stress is oriented N058°E/45°NE.

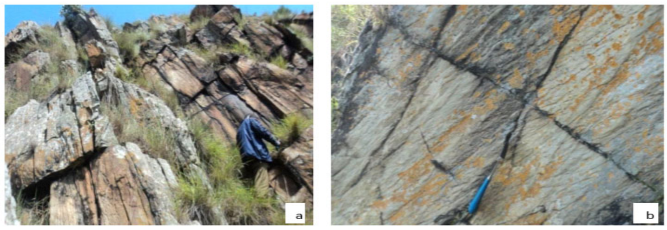

Figure 7 (a and b): Network of joints and joints affecting the quartzites on Mount Nyabalenga

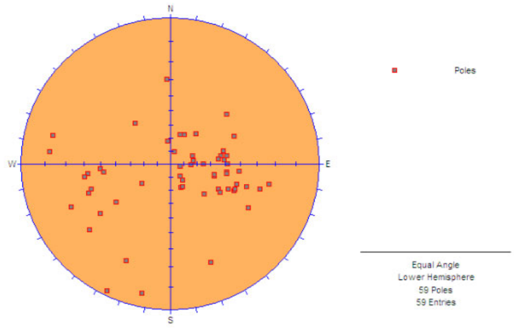

Figure 8. Stereographic diagrams of joint poles on stereonet

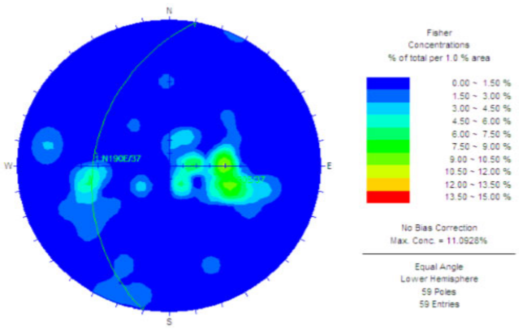

Figure 9. Diagram of cyclographic traces of joints

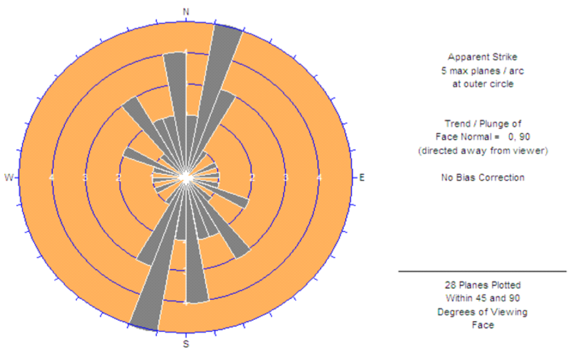

Figure 10. Joint frequency rosette

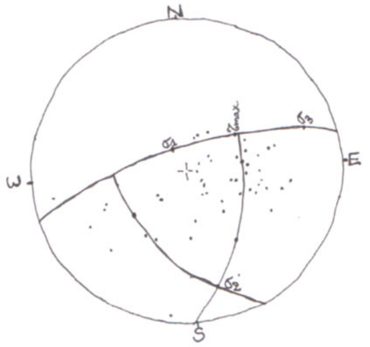

Figure 11: Determination of joint stresses (Wulff canvas, lower hemisphere)

Veins F2: In the study area, the veins mainly affect sandstones and quartzites. These are preferentially fractures mineralized in quartz and exceptionally in amethyst (Fig. 12). The stereographic projection of the poles of the attitudes of the quartz and amethyst vein planes shows a concentration of the poles in the NE and SE quadrants. Thus, two poles P1 and P2 oriented respectively N028°E/040°ESE and N051°E/60°NW. The average attitude of the vein planes is N200°E and dip 54 WNW (Fig. 13). This direction is subparallel to that of the layers. Most of the raised sills are therefore layered sills. The arrangement of the poles or cyclographic traces of veins in the four quadrants of the stereogram testifies to a folded structure in domes and basins (Fig. 14). For veins, the maximum concentration is 12.5%. The frequency rose window highlights four major families of veins (Fig. 15):

- A family of direction N 350° to 360°E;
- A family of direction N 00° to 10°E;
- A family of direction N 10° to 20°E;
- A family of direction N 20° to 30°E.

By plotting the results of the measurements of each vein on the stereographic canvas, we determine the orientation of the stress vectors having generated the discontinuity (Fig. 12). Thus, we have the major principal stress ((N014°E/68SSW), the intermediate principal stress ((N047°E/010°NE) and the minor principal stress (N134°E/11NW). The tangential stress maximum is oriented N124°E/53°WNW (Fig. 16) By superimposing all the poles of the fractures (mineralized or not) on the canvas of the major fold, we were able to determine the at least relative chronological relationships between the planes of the fractures. fractures and the axial plane of the major fold (Fig. 17). To do this:

- The poles which fall either on the axial plane, or near it, group together the fractures (mineralized or not) which are synchronous to the major fold, that is to say the joints and the veins whose directions vary between N070° E and N115°E;
- The poles which, relatively, move further away from the axial plane of the major fold group together the joints and veins which were formed either before or after the major fold in the sector.

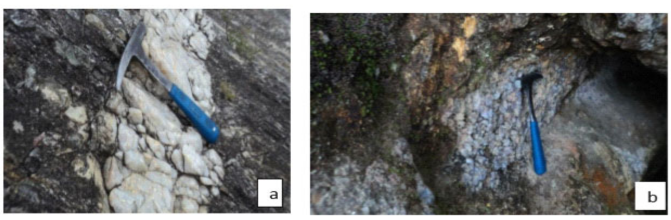

Figure 12. Veins of quartz (a) and amethyst (b) in sandstones

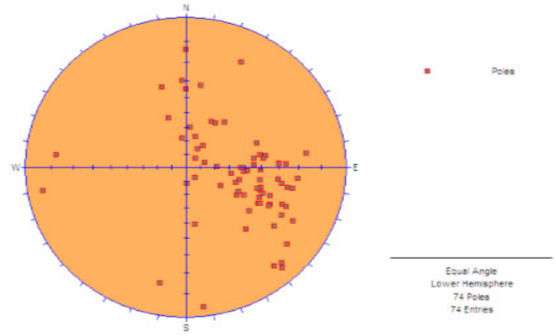

Figure 13. Stereographic diagram of the poles of the veins

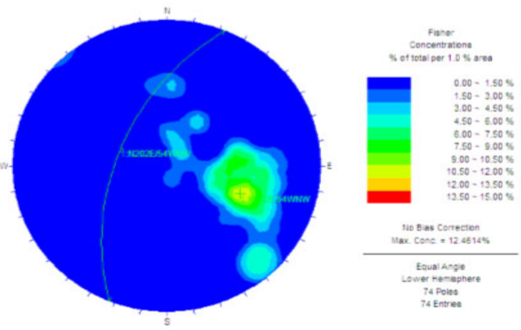

Figure 14. Diagrams of cyclographic traces of vein plans

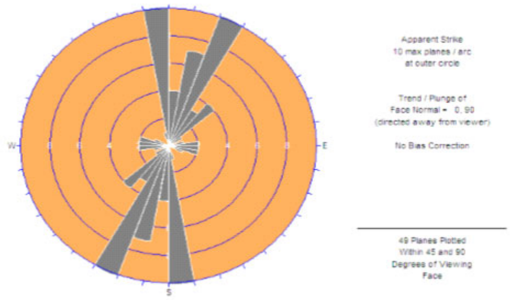

Figure 15. Frequency rose window for all the veins

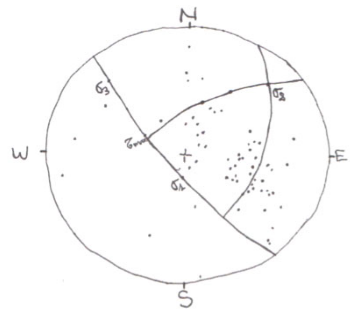

Figure 16. Determination of stresses from veins (Wulff canvas, lower hemisphere)

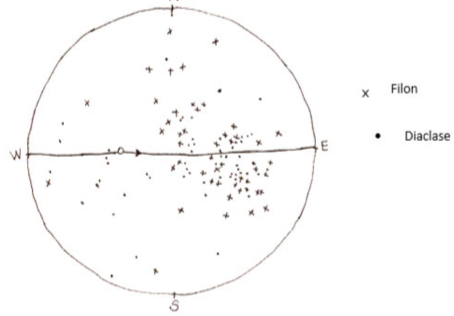

Figure 17. Distribution of the poles of the joint planes and veins relative to the axial plane of the major fold oriented NW90°E/45°S

Geological map

The census of the outcrops and the reporting of their extension on a topographic plan (contour curves extracted from SRTM DEM data available on the USGS site) produced the outcrop map. By tracing or correlating the different outcrop stations, we were able to determine the contacts between the six major lithological units (sandstone, schists, quartzite, conglomerate, basalt and trachyte) and thus draw up a more or less detailed geological map of the sector at a scale of 1/12500 (Fig. 18). On the structural level, taking into account the directions of the dips of these lithological units, three major folds (two synclines and an anticline) were identified on the geological map depending on whether the dips diverge or converge. Furthermore, the geological map also highlights the microfaults (dextral and semi-lateral) identified in the study area (Fig. 18).

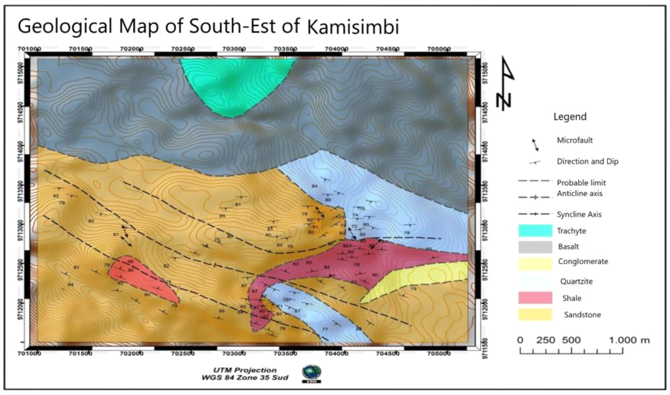

Figure 18. Geological map of the South-East sector of Kamisimbi

Conclusion

From this study, the analysis of deformation in the Middle Kibarian was carried out in the sub-Saharan zone (South Kivu; DR Congo) in order to better understand it and update its geological history. The main results of the lithological inventory and structural analysis (tectonic context) carried out in the South-East of Kamisimbi lead to the following conclusions:

a) Lithological inventory

In the South-East of Kamisimbi, three lithological groups, mainly sedimentary (conglomerates and sandstones), metamorphic (schists and quartzites) and volcanic (basalts and trachytes) have been inventoried.

b) Structurally

The South-East of Kamisimbi was affected by three (03) main phases of deformation (D1, D1' and D2). Phases D1 and D1' (shear phase) folded, then sheared the South-East of Kamisimbi giving structures with an axis from WNW-ESE or E-W to NW-SE and N-S. The essentially ductile D1 deformation phase includes F1 foliation, S1 schistosity and P1 folds in shales and sandstone shales with low to medium dips (10° – 47°). It shows two major directions E-W and WNW-ESE. It also includes P1 microfolds, two of which, oriented N087°E and NO84°E, are more or less parallel to the major folds to which they are linked. The microfold oriented N046°E would have a sedimentary origin (Slump), non-tectonic. The deformation phase D2, both posterior and intersecting with the first two D1 and D1', is the most marked in the study area. It is identified in almost all rocks and results in fractures, whether sustained or not, mainly D2 joints, J2 joints, F2 veins and veins. On a regional scale, the first phase D1 and the second D1' defined in the South-East of Kamisimbi would correspond respectively to phases D2 and D2' of Kibarian deformation where the structures are oriented NW-SE; WNW-ESE to E-W.

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