# A Review of Structure and Evolution of the Nyamukubi Area, Western Part of Lake Kivu - South Kivu Province, Democratic Republic of Congo

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*Keywords:* deformation, stress, fault, fold.

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# A Review of Structure and Evolution of the Nyamukubi Area, Western Part of Lake Kivu - South Kivu Province, Democratic Republic of Congo

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*The western part of Lake Kivu has been described through geological campaigns and hypotheses relative to origin, the nature of rocks and tectonic events have been discussed. Field investigation and outcrops description has revealed that Quartzite, Schist, Gneiss and Granite are the most spread rocks around the area. The research undertaken allowed us to make emphasis on rocks deformations in Nyamukubi area, we have described geological structures such as lineaments, joints, and faults and their geometric measurement were noted. The analysis in the field was done using the stereographic projection. Geological investigations suppose that Nyamukubi is built on a basement terrain made by Precambrian metamorphic rocks intruded by granites. The structural analysis supposes that the Kibarian erogenous has transformed the geological material into fold and fault and the rift event have completed by setting up a normal faulting morphology. According to the result of the structural analysis, it was found that the Nyamukubi area has been deformed by a compressional NE-SW constraint. These compressional stresses might be originating from the Mesoproterozoic kibarian erogenous whose results are still observed through geological materials and forms. However, some extensional movement markers such as veins and normal faults were identified and described. The structural analysis of quartz veins supposes that they are the result of the post orogenic granites whose fluids filled the fractures left by the Kibarian erogenous; these are mineralization containers.*

*Keywords:* deformation, stress, fault, fold.

## I. INTRODUCTION

Kivu in the Democratic Republic of Congo has a long-attracted interest of geologists due to the occurrence of large mineral deposits; it's among the most tin-mineralized zone in Africa. Several geological surveys made the last decades through the exploratory campaign by mining companies and scientific researchers. The geology of the Kivu area has been studied to various degrees. The research of (Boutakoff, 1939; Lhoest, 1964; Kampunzu, 1991; Villeneuve, 2006; Dewaele, 2010; Shungu, 2016) have proved that most of Kivu geological formations are Precambrian; their lithology are dominated by metamorphic and granitic rocks. The investigations (Dewael, 2010) on the Rutongo mineralization attribute to the Kibarian erogenous in association with the rifting events most of the region's deformations. The Kibarian erogenous has transformed the major part of the great lake region into folding and faulting systems. Numerous models exist concerning the origin of the Mesoproterozoic Kibara belt. It has been interpreted as a collisional orogeny (Kampunzu et al., 1986, Rumvegeri, 1991), as an intracratonic orogen with different periods of extension and compression (Klerkx et al., 1984, 1987), and as an intracratonic extensional detachment structure, conditioned by strike-slip reactivation of NW trending shear zones in the Paleoproterozoic basement (Fernandez-Alonso & Theunissen, 1998, Dewael, 2010). The nowadays morphology of the eastern DR Congo is supposed to result from the combined action of the Kibarian erogenous and

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the rifting. Rifting is a fundamental tectonic process that controls the break-up of continents, the development of passive margins, and the initiation of ocean basins. Rifting provides the conditions needed to produce oil and geothermal resources and is often associated with volcanic and seismic hazards. Many features in rift zones and passive margins have been successfully explained by lithospheric stretching models (McKenzie 1978; Wernicke 1981; Lister et al. 1986; Whitmarsh et al. 2001), which assume that lithospheric thinning and crustal extension are driven by far-field stresses from plate motions. Recent studies (Hendrie et al. 1994, Ebinger and Ibrahim 1994, Theunissen et al. 1997, Nielsen et al. 1999) have shown that some parts of the East African Rift System cuts and/or reactivates known Precambrian shear zones, Permo-Triassic, cretaceous or Paleogene rift basins. However, the spatial extent of these earlier structural systems is poorly known. By the rifting, the geological structure made by the kibarian erogenous have been broken into hosts and grabens with several fractures. Villeneuve, 2006 has found that most of Kivu's geology resembles the Itombwe syncline which lithology is constituted by metamorphic rocks and granite. Till now there are several problems about the structure and the location of the periclinal closure to the south of the Itombwe syncline, even though this structure is depicted very well in the older geological maps. During the last decade an essential quantity of Colombo-tantalite has been discovered in the northern Nyamukubi area; the Nyabibwe sector is known as a Nb-Ta and tin veiny mineralized zone, but the origin and form of the ore body were still unknown. The geological investigation around Nyamukubi where Grossmans, 1938 evidenced for the first time the lead veins mineralization has pointed out that this sector is fractured but the structural approach has not been developed. This synthesis was made to understand the origin and nature of the principal deformations around the Nyamukubi area, locating them in time according to the main geological events which have affected the great lake region in the past. The assessment was based on the geological and structural mapping in the area, identification and characterization of geological structures, structural modeling and hypothesis establishment comparatively with the ancient geological research around the great lakes area.

## II. MATERIALS AND METHODS

### *2.1 Description of the Study Area*

#### *2.1.1 Geographic background*

The surveyed area is a part of the Kalehe territory in the south Kivu province. It's located in the western part of Lake Kivu between the Nyabibwe and Bushushu areas. With tropical climate, the weathering of geological materials is dictated by either a long rainy season or the topographic factor. The soil is sandy clayed; it is used for agricultural activities.

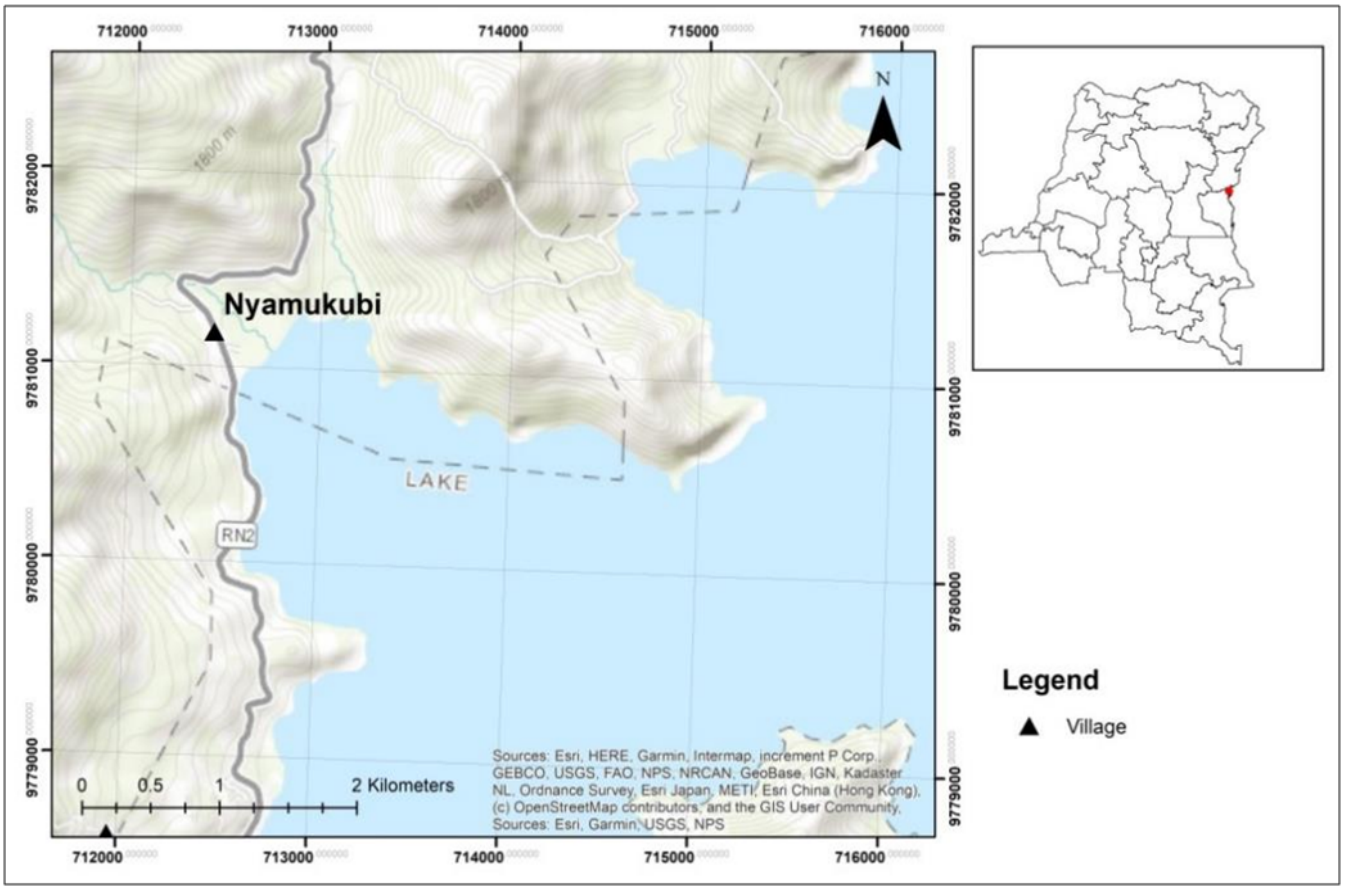



*Figure 1:* Location of the Nyamukubi area in the western part of Lake Kivu, crossed by the national road RN5, this road links the two most significant towns of the Eastern part of DRC, Goma and Bukavu through, Kalehe and Masisi territories.

### *2.1.2 Geological Settings*

The South-Kivu Rift morphology is a fault step one made by a succession of either fault blocks or horsts and grabens progressively levelled from the exterior to the interior of the Rift (Ilunga L. 1991). The western rift valley is an arcuate zone of contrasted relief with large deep lakes, fertile valleys, steep mountains and high plateaus affected by volcanism, earthquakes and landslides (Delvaux, 2016). It is known that Kivu area is built on a crystalline fractured basement, and the mineralization is contained in quartz veins. A thick NS mixtite was recognized in the area between Kahuzi and Nyamukubi (Villeneuve, 1976). Several authors (Boutakoff, 1954; Lhoest, 1964; Kampunzu, 1991; Villeneuve, 2006, Dewael, 2010) agree that most of the Great Lake region geology is due to the Kibarian orogeny whose age is Precambrian. The Kibara orogen formed and evolved between two pre-Mesoproterozoic domains: the Archean Paleoproterozoic Congo craton to the west and the north, and the Archean and Paleoproterozoic Tanzania craton and Bangweulu Block to the east and the south. The Kibara belt consists of two distinct segments, separated in the Kivu area of the Democratic Republic of Congo by the northwestern extension of the Paleoproterozoic Ubende belt (SW Tanzania) across Lake Tanganyika. The "Northern" (Rwanda, Burundi, Maniema, and Kivu in the DRC) and "Southern" (Katanga in the DRC) segments should be viewed as two separate albeit coeval orogenic belts (Tack et al., 2002a, 2002b, 2006, Dewael, 2010). It is made by metamorphic rocks intruded by different generations of granite (Cahen et al., 1984). Several studies (Agassiz, 1954; De Kun, 1954, 1959; Legraye, 1955; Peeters, 1956; Safiannikoff, 1955; Steenstra, 1967; Varlamoff, 1948, 1950, 1954a, b, c, 1956, 1961, 1963, 1969, 1975, Günther, 1990; Pohl, 1994; Pohl & Günther, 1991; Dewaele et al.,

2007a, 2007b, 2008, 2010; De Clerk et al., 2008) in the Kivu mineralization suppose that the origin is mostly due to the Kibarian G4 granite whose outcrops were seen and described in Kalehe territory by Boutakoff 1939, they are commonly called Hango and Sula granite. These granites are supposed to be the source of several mineralizations in the Kalehe and Masisi territories. In the last decade different mineralization was discovered in Nyamukubi area and the surrounding villages, but the origin and the ore body form are not well known till now.

### *2.2 Methods*

Geological mapping was carried out to understand the significant structural features in the study area. The research provides the structural analysis of rock deformations in the surrounding mountains of the Nyamukubi area including structures such as joints and faults have been identified and their orientations noted. Rock outcrops were located and examined, and characteristics such as rock composition, description of designs, and textures, including analyses of their temporal and space relationships; external design and fossil content were recorded. Emphasis was placed upon systematic field observations, accurate measurement of the orientation of structural elements, and sketching and photographing the structures. The structural measurements were carried out using the compass-clinometer Sylva 15T. At each metamorphic rock, geometric measurement such as dip and rock direction were noted, and analysis in the field were done using the stereographic projection. Field data have been classified according to their nature and the supposed origin. The measured azimuths were plotted using the Win-tensor software for characterizing the principal movement comparatively to the main known geological events in the Great Lake area. Hypotheses have been formulated based on the field description, computer plotting, and the known geological history of the area.

## III. RESULTS AND DISCUSSIONS

The main goal of structural geology is to use tectonic measurements of rock anisotropy to uncover information about the history of rock deformation and understand the regional stress field (Pavel Hanzl &Krystof Verner., 2018). Field investigations revealed several lithological units in the study area, including granites, granite gneiss, quartzite, schists, and limestone. The structural analysis was supposed to make emphasis different discontinuities, which includes foliation, joints, Veins, folds, and faults. While describing outcrops, emphasis was placed on the petrographic nature of rock and geometric measure.

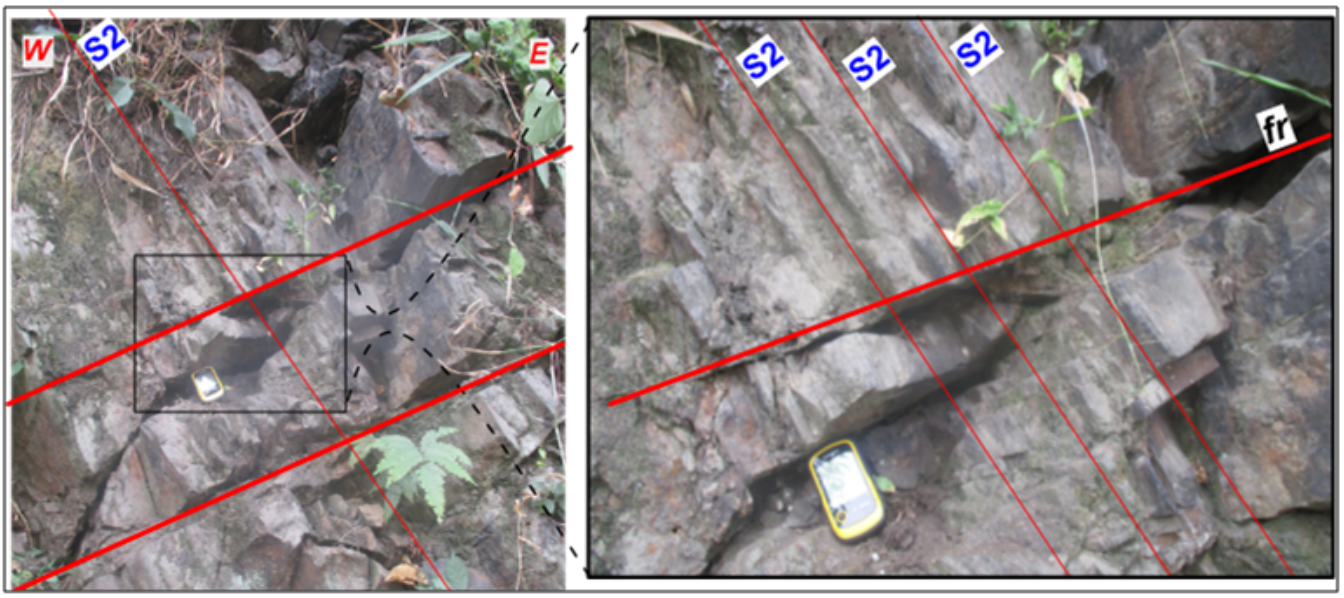



*Figure 2:* Outcrop of schist with foliation symbolized by S2 and joints by fr.; at this station, joints are perpendicular to foliations. The geometric measurement of the foliation is N115°E/80°NNE and parallel joints are oriented N76°E/67°NNW.

These foliations are supposed to be the result of Kibara erogenous 1350 - 1260 Ma (Lavreau, 1984). The compressional stress during this geological event has transformed the former sediments into folded metamorphic rocks. Most of the folded materials have been intruded by granits (Cahen et al., 1979). The "Northern" (Rwanda, Burundi, Maniema, and Kivu in the DRC) and "Southern" (Katanga in the DRC) segments should be viewed as two separate albeit coeval orogenic belts (Tack et al., 2002a, 2002b, 2006, Dewaele et al, 2010). Numerous models exist concerning the origin of the Mesoproterozoic Kibara belt. It has been interpreted as a collisional orogeny (Kampunzu et al., 1986, Rumvegeri, 1991), as an intracratonic orogen with different periods of extension and compression (Klerkx et al., 1984, 1987), and as an intracratonic extensional detachment structure, conditioned by strike-slip reactivation of NW-trending shear zones in the Paleoproterozoic basement (Fernandez-Alonso and Theunissen, 1998).

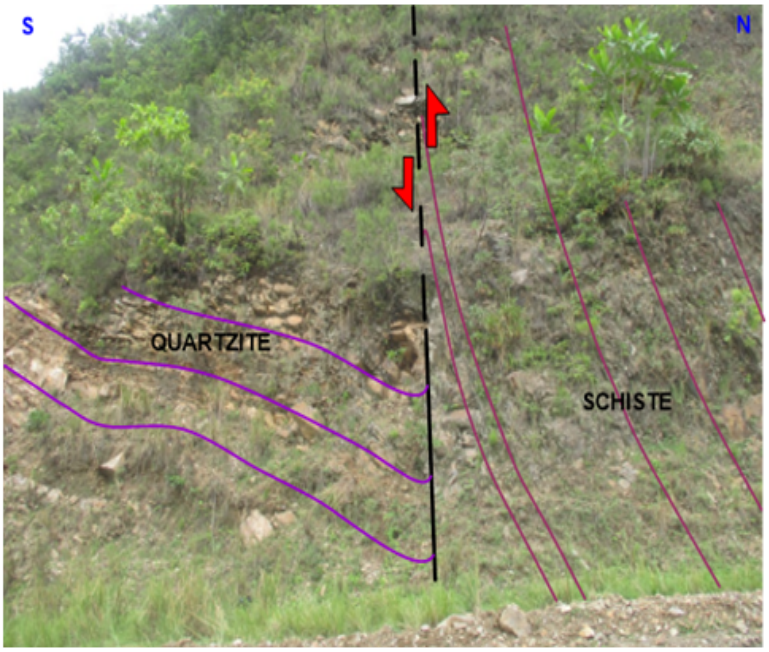
The described foliations are the result of this geological event; they have been used to find out the direction of stresses whose consequences was the kibarian mountains as known from the northeastern to southeastern of the Democratic Republic of the Congo. Nyamukubi geology is made by folded and faulted metamorphic rocks whose general direction was recognized while interpreting field data. The structural measures of foliations presented at this outcrop, were plotted in the Wintensor software. The general constraints of deformation are compressive oriented from NNE to SSW.

*Table 1:* Measured attitudes of foliations on the field

| PLAN 1 | | PLAN 2 | |
|---|---|---|---|
| Azimut | Dip | Azimut | Dip |
| 24 | 42 | 78 | 34 |
| 194 | 14 | 20 | 18 |
| 198 | 17 | 52 | 22 |
| 24 | 43 | 52 | 22 |

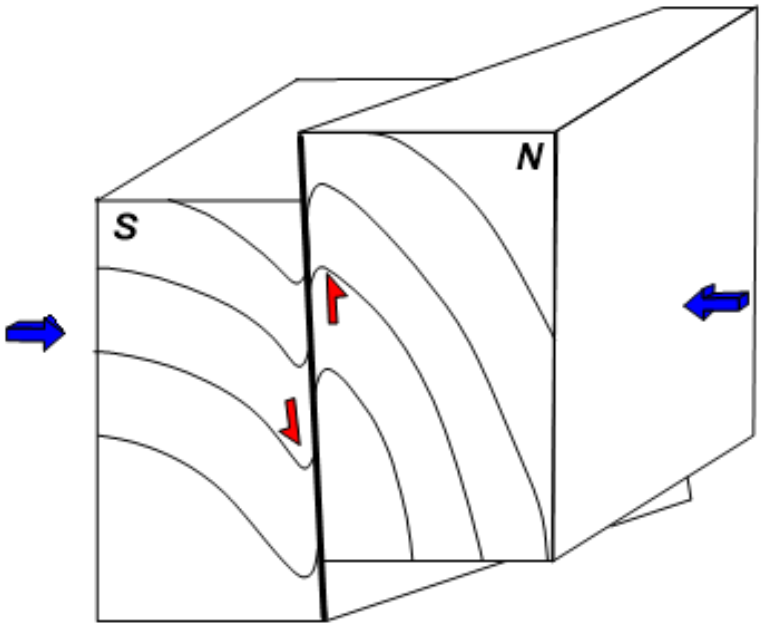

*Figure 3:* Folded schist at Bushimba Mountain. At this station, the dip of foliation changes from N82°SSW to 42°SSW. The general constraints at these stations are compressive, and oriented NNE-SSW.

The upper described outcrops are folded schists. However, the geometric analyses of the layer's continuity at these outcrops show the movement of blocs. Sedimentary accumulations are greatest near the central part of the border-fault segment and decrease toward the tips. This movement is supposed to result from a fault event whose origin is justified by the geological history of the African Great Lake's geology. This was controlled mainly by old basement structures in series of successive tectonic stages that reactivated the Neo-proterozoic basement (Delvaux, 2016). Recent analyses of gravity data from East Africa suggest that thermal processes and faulting have weakened the lithosphere beneath the Western rift valley relative to that beneath the uplifted craton (Ebinger et al., 1989). The East Africa rift system is a significant tectonic zone that separates the Nubian plate from the Somalian plate (Delvaux, 2016). The structural analysis undertaken in the Nyamukubi area supposes that the Kibarian erogenous has transformed the area into folded and faulted systems and the rift event has completed by setting up a normal faulting morphology. Since the end of the Pan-African orogeny (600-500 Ma), the history of the significant part of the African plate has mostly been chiefly by the development of domal uplift and rifting, leading sometimes to continental drift (Kampunzu and Lubala, 1991). The Nyamukubi fault, as described is among the most considerable faults in Kivu. This NS geological weakness can be the source of various landslides often observed in the vicinity of Nyamukubi, in the Bushushu area. Smets et al., 2016 believe that a better understanding of the fault distribution in the Kivu segment is required as active faults play a role in the distribution and occurrence of the main natural hazards encountered in this region.

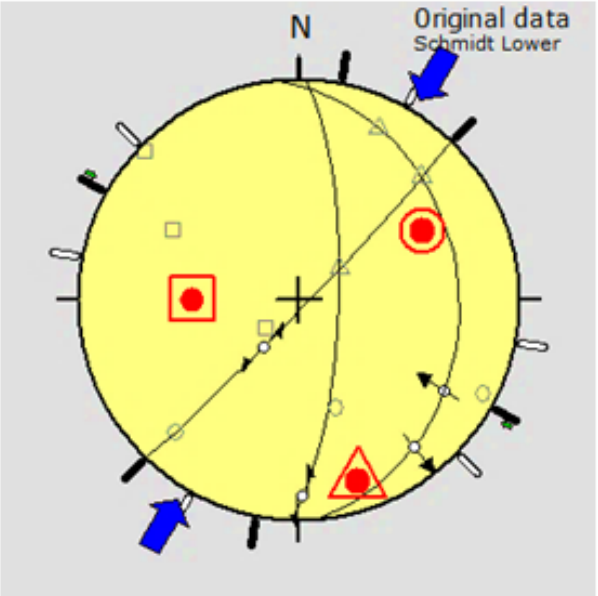



A

The computer plotting of the attitudes of foliations supposes that NNE-SSW stress has transformed this station on a folded quartzite, and the model of the faulting is presented below.




B




*C*

*Figure 4:* Vertical fault in Bushimba Mountains (A) stretched (B) and modelized (C) using the win-tensor software. The structural analysis supposes the area has been affected by compressional NNE-SSW constraints and deformed by faulting.

However, the structural analysis undertaken on quartz veins supposes an extensional movement. These are considered to be originating from the post-orogenic (Kibarian) granite intrusion event. When describing metamorphic rocks in the field we inevitably encounter plutons whose relations to deformations turns out to be important, if not a critical, part of the geological history of the area. Plutons are incredibly important because they generally provide us with the most straightforward way to determine the relative age of deformation (Georges H. Davis and Stephen J. Reynolds. 1996). This Kibarian orogenic belt forms a large metallogenic province that contains numerous granite-related ore deposits, which is rich in minerals like cassiterite, columbite-tantalite, wolframite, beryl, spodumene, amblygonite, monazite and Gold (Dewael et al. 2010). They are present in a different type of mineralization but the Nyamukubi mineralization's are made by quartz veins. The structural analysis of veins has allowed us to distinguish three families of veins according to their directions. The modal direction of veins in the Nyamukubi is the NE-SW direction. This is followed by the NNE-SSW. The third family of veins is from the NW to SW, perpendicular to the modal direction.

*Table 2:* Measured attitudes of veins from the field

| Station No. | AZMUTHS | DIP |
|---|---|---|
| 1 | 235 | 50 |
| 2 | 232 | 52 |
| 3 | 234 | 51 |
| 4 | 238 | 50 |
| 5 | 234 | 48 |
| 6 | 246 | 53 |

| | | |
|---|---|---|
| 7 | 20 | 65 |
| 8 | 20 | 60 |
| 9 | 353 | 90 |
| 10 | 275 | 40 |
| 11 | 282 | 52 |
| 12 | 284 | 64 |
| 13 | 197 | 57 |
| 14 | 204 | 63 |
| 15 | 209 | 44 |
| 16 | 180 | 68 |
| 17 | 312 | 70 |
| 18 | 310 | 73 |
| 19 | 314 | 72 |

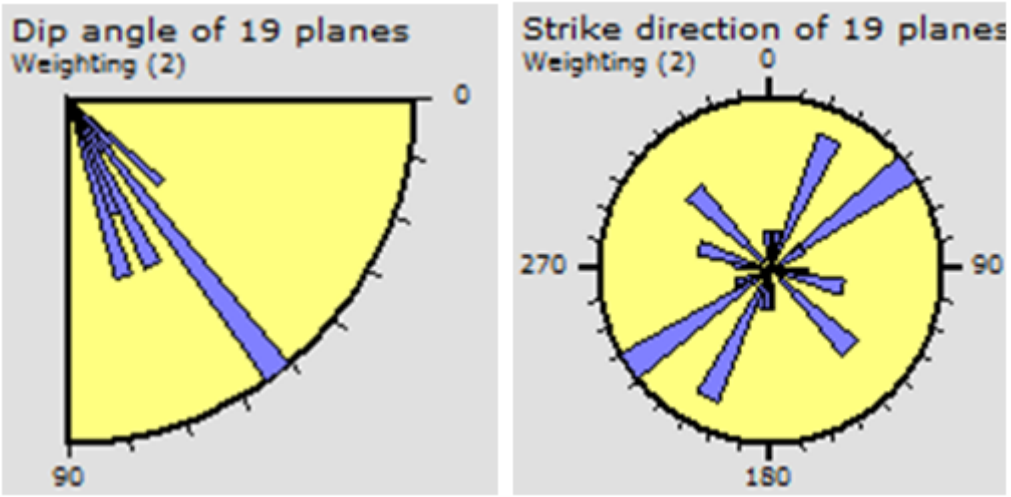



*Figure 5:* Rose diagram showing measures attitude of veins in the field

The measured azimuths of foliations were plotted using the Win-tensor software for characterizing the principal movement comparatively to the main known geological events in the Great Lake area.

*Table 3:* Measured attitudes of foliations plans from the field

| PLAN 1 | | | | PLAN 2 | | | |
|---|---|---|---|---|---|---|---|
| DIRECTION | | DIP | | DIRECTION | | DIP | |
| DEGRES | AZIMUT | | DEGRES | DEGRES | AZIMUT | | DEGRES |
| N132 | 42 | 55°NE | 55 | N114 | 24 | 24°NNE | 24 |
| N104 | 194 | 82°SSW | 82 | N110 | 20 | 18°NNE | 18 |
| N114 | 204 | 42°SSW | 42 | N138 | 48 | 34°NE | 34 |
| N94 | 4 | 85°N | 85 | N52 | 322 | 22°SE | 22 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| N156 | 66 | 75°ENE | 75 | N142 | 52 | 22°NE | 22 |
| N86 | 176 | 35°S | 35 | N168 | 78 | 72°ENE | 72 |
| N96 | 186 | 30°S | 30 | N145 | 55 | 50°SW | 50 |
| N115 | 25 | 80°NNE | 80 | N76 | 346 | 67°NNW | 67 |
| N42 | 312 | 70°NW | 70 | N98 | 8 | 75°NNE | 75 |
| N74° | 344 | 55°NNW | 55 | N132 | 42 | 43°NE | 43 |
| N130° | 40 | 65°NE | 65 | N42 | 132 | 18°SE | 18 |
| N85° | 355 | 28°N | 28 | N170 | 260 | 18°WSW | 18 |
| N92° | 2 | 75°N | 75 | N172 | 262 | 16°WSW | 16 |
| N101° | 11 | 82°N | 82 | N178 | 268 | 12°WSW | 12 |

By plotting the geometric data according to their supposed origin (mechanic or tectonic) using win tensor software, it was discovered that the general stress of deformation in Nyamukubi sector is compressive oriented from the Northeastern to the Southwestern. This direction is represented on the graph (fig. 6) by bleus arrows; the red circle with a central point represents the principal stress $\sigma_1$ whose direction is N048° and 31° dip; the other stresses $\sigma_2$: 13/310 and $\sigma_3$: 56/200 are respectively represented by triangle and a square.

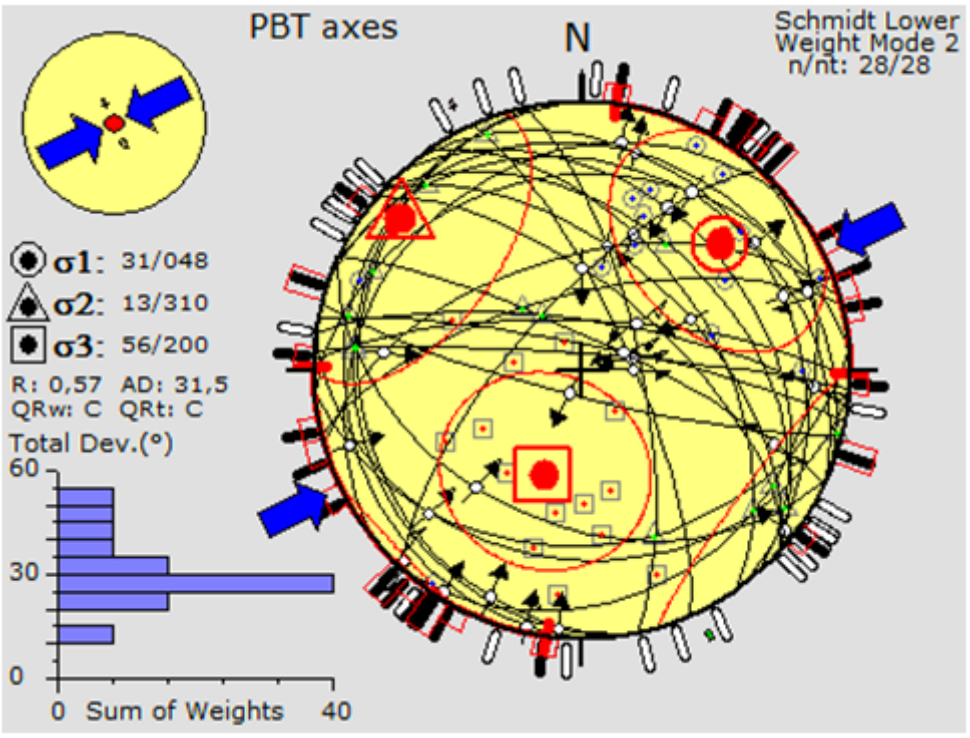



*Figure 6:* Rose diagram showing stresses orientation in the Nyamukubi area; it is a NE-SW compressional stress

The compressional stresses haven't been surprisingly found in the Nyamukubi sector because several geological researches (Boutakoff, 1954; Lhoest, 1964; Kampunzu, 1991; Villeneuve, 2006; Dewael, 2010; Shungu, 2016) in the Great Lakes regions attributed to the Kibarian compressional stress the origin of folds and faults. The geological investigations around the Itombwe syncline, where Lhoest evidenced for the first time, an unconformity between an upper sedimentary group and a lower metamorphic complex, are an example of a folded kibarian belt. The research undertaken by Villeneuve et al., 2004; distinguished twenty NNE-SSW folded

formations with some exceptional NW-SE. The NE-SW stress direction found in the Nyamukubi area is not so far from the NNE-SSW as discovered when Villeneuve has described the Itombwe synclines. However, we cannot yet consider the Nyamukubi sector as a part of Itombwe syncline , but we would like to deepen our research in order to situate chronologically the Nyamukubi sector comparatively with the Itombwe synclines.

## IV. CONCLUSION

The review and the analysis of structures have been discussed through geological investigations and computer plotting using the win-tensor software. Field investigations revealed several lithological units in the Nyamukubi area, including granites, granite gneiss, quartzite, schists, and limestone. The structural analysis was supposed to highlight different discontinuities. Emphasis was placed upon systematic field observations, accurate measurement of the orientation of structural elements, and sketching and photographing the structures. The field observation and outcrops description have allowed us to discover different discontinuity such as fault joints and veins. In this village of the South Kivu province, the NE-SW compressional stress has transformed geological material into folded and faulted metamorphic rocks. This is supposed to be originating from the Mesoproterozoic Kibarian erogenous. The structural analysis of veins has evidenced different families according to their directions. The principal direction of veins in the Nyamukubi is NE-SW. Its followed by NNE-SSW. The third family of veins is from the NW to SW, perpendicular to the modal direction. Veins and joints are not essentially originating from the Kibara erogenous ; they can be from either the post-orogenic granite or the rifting event. The history of the Nyamukubi area can be understood as a result of Kibarian erogenous, whose consequences have been described as the origin of metamorphic rocks whose outcrops have been observed and described through geological investigation. The Kibarian erogenous has transformed the former Paleoproterozoic sediments on a folded metamorphic complex whose core has been filled by granites. These post-orogenic granites are supposed to be the origin of mineralization in the whole region of Kivu. The nowadays morphology of the Nyamukubi sector can be understand as the result of the combined action of the kibarian compressional stresses and the extensional stresses due to the rifting event. This study will be continue through geochemical and metallogeny approaches.

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