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Influence of Regional Tectonics on The Geological Formations of The Locality of Mabuku In Beni Territory

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Abstract: The locality of Mabuku is located in the eastern DRC, in a landscape where tectonic effects are visible. The main cause of this environmental disturbance is known as tectonics. This study aims to determine the influence of regional tectonics (like Kibalian, Ruzizian and Kibarian tectonics) on rocks of the locality of Mabuku, and their types. After the fieldwork and the data processing, we got the following results: firstly, none filled faults were due to constraints of the compressive type, which are also similar to those affecting the formations of the group of Ruzizi. Secondly, the schistosity of these rocks was due to extensive type stresses and its direction is similar to Kibarian tectonics. Moreover, the veins were generated by a constraint of the compressive type, bounding them to Kibalian tectonics. In conclusion, in the locality of Mabuku there's a combination of the Ruzizian, Kibalian, and Kibarian tectonics.

Keywords: tectonic, kibarian, Kibalian, Ruzizian, Mabuku

INTRODUCTION

The tectonic sketch of the Belgian Congo and Ruanda-Urundi published by the Geology Commission of the Ministry of the Colonies in 1952 shows that in most of the regions under review, the Precambrian basement was affected by two successive tectogenesis. The first concerns the Ruzizi group: it is the Ruzizian folding; the second, the Urundi group: this is the Urundian folding. It is moreover on the basis of these two tectogenesis that the division into two groups is currently accepted(Cahen, 1952; Delvaux & Barth, 2010).

Generally, the tectonic directions (axial directions of the folds) are divided into two sets (Figure 1): NW-SE to WNW-ESE for the Ruzizi group, NE-SW for the Urundi group (Delvaux & Barth, 2010; Dewaele et al., 2016). These two directions intersect almost orthogonally in the Itombwe region (Lohest, 1946; Lepersonne, 1949; Safianikoff, 1952). However, they undergo remarkable changes (Fernandez, 2015). Thus, the direction of the layers of the Ruzizi group straightens towards the North in the western part of Ruanda-Urundi close to the Ruzizi. Then, these layers cross Lake Kivu and meet in an NW direction on the western shore of the lake (Denaeyer, 1951)

Towards the North, the Urundian folding continues in Ruanda-Urundi and in Uganda, but the whole draws a vast virgation towards the NW (Lepersonne, 1949; Cahen, 1952; Villeneuve, 1987; Rumvegeri, 1991). As for the Kibali group which appears in North Kivu (Figure 1), its axial directions are, on the whole, WNW-ESE to WSW-ENE, therefore distinct from the main directions of the two preceding groups(Lepersonne, 1949). It seems to correspond to an equally distinct tectogenesis which would be placed between the Ruzizian tectogenesis and the Urundian tectogenesis (Denaeyer, 1951; Delvaux & Barth, 2010).

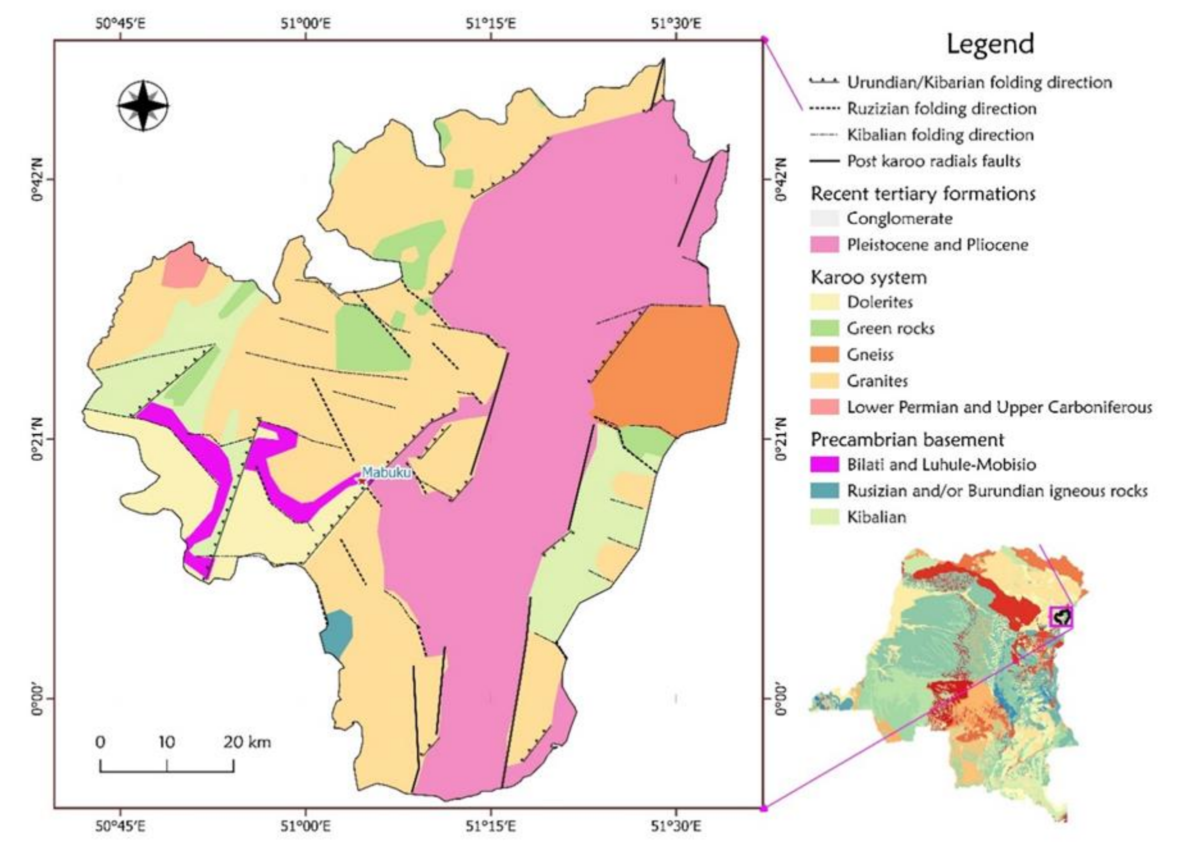


Figure 1. An extract of the geological map of the eastern part of D. R. Congo, with a focus on the geology of the territory of BENI (Denaeyer, 1951)

The result of these epirogenic movements was the division of the region into a series of compartments, some raised (horst) of which the most majestic example is the Ruwenzori massif, the others collapsed (graben) into steps arranged in relays (Lavreau & Ledent, 1975; Rumvegeri, 1991; Dabo & Aïfa, 2013). In Kivu, the raised blocks are often limited to the east by imposing scarps of faults (Kamaniola, Nyamukubi, Sake, Mt. Kisale, Kabasha, Beni) which have their counterpart, more attenuated, on the other bank of the graben, Rwanda and Uganda (Lepersonne, 1949; Denaeyer, 1951; Cahen, 1952)

Through this study, we want to determine the influence of regional tectonics (such as Kibalian tectonics, Ruzizian and Urundian tectonics) on the geological formations of the locality of Mabuku, and to specify the types of constraints having acted on these formations and their directions.

METHOD

Field work

The fieldwork consisted of taking structural measurements of veins, faults and schistosity planes. The work sites were located using an Etrex GPS (Global Positioning System), with an accuracy of 3m. The geographic coordinates were taken in the format of UTM (Universal Transverse Mercator) units. The Sylva brand compass was used to take structural measurements (direction and dip) of formations encountered in the field. Structural measurements were taken using the right-hand method.

The locality of Mabuku is located west of Maboya (about ten kilometers from the city of Butembo, on the Butembo-Beni axis), in the chiefdom of Bashu, Territory of Beni, in the province of North- Kivu in the DRC (Figure 2).

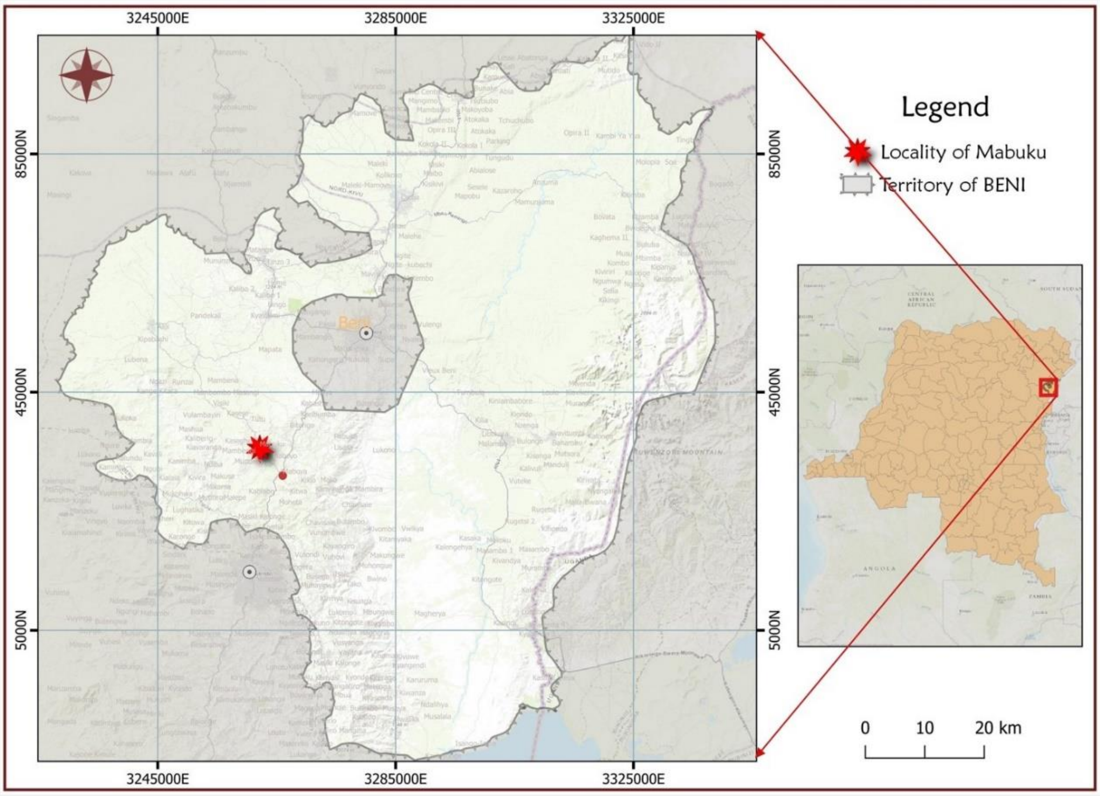


Figure 2. Location map of the locality of MABUKU, in the Territory of Beni.

Data processing

The data processing was done by the software: Excel 2013, Dips, Win-tensor (version 5.9.3) and QGIS (version 3.16). The Excel 2013 software made it possible to enter the raw data before any processing within the Dips, Win-tensor and QGIS software. For the processing of the structural measurements, the Dips software allowed us to find the preferential direction and the diagram of the densities; and the Win-tensor software was used to determine the orientation and nature of the stresses. For cartography, the QGIS (version 3.16) software was used to produce the location map of the study area using the RGC database and a combination of ESRI world topo and Open street map.

Interpretation

Stress inversion results are represented by the orientation of the 3 principal stress axes (a black dot surrounded by a circle for $\sigma 1$, a triangle for $\sigma 2$ and a square for $\sigma 3$). The related SHmax and Shmin orientations are represented by large arrows outside the stereogram. Their type, length and colour symbolise the horizontal deviatoric stress magnitude relative to the isotropic stress (σi) and are in function of the stress regime and the stress ratio $R=\sigma 2-\sigma 3/\sigma 1-\sigma 3$. Red arrows when $\sigma 3$ is subhorizontal (always Shmin), green arrows when $\sigma 2$ is subhorizontal (either Shmin or SHmax), bleu arrows when $\sigma 1$ is subhorizontal (always SHmax). Outward arrow indicates extensional deviatoric stress ($b\sigma i$) and inwards arrows, compressional deviatoric stress ($N\sigma i$). The vertical stress (σv) is symbolised in the small circle with stress arrows on the upper left corner of the figures by a solid circle for extensional regimes ($\sigma 1 \approx \sigma v$), a dot for strike-slip regimes ($\sigma 2 \approx \sigma v$) or an open circle for compressional regimes ($\sigma 3 \approx \sigma v$)(Clark, 1989; Delvaux & Barth, 2010).

The histogram on the lower left corner of the figures represents the distribution of the misfit angle α (Slip deviation, SD), weighted arithmetically according to the magnitude. The contribution of data with misfit angles N65° are all summed up and represented together along the vertical axis between α at the 60–65° interval (sites 6b, 8, 16, 17, 23). The bars outside the stereogram represent the SHmax (black) and Shmin (white) directions for individual focal mechanisms and the small grey symbols inside, the orientations of the related kinematic axes (circle: p axis, triangle: b axis, square: t axis) (Delvaux & Barth, 2010).

RESULT

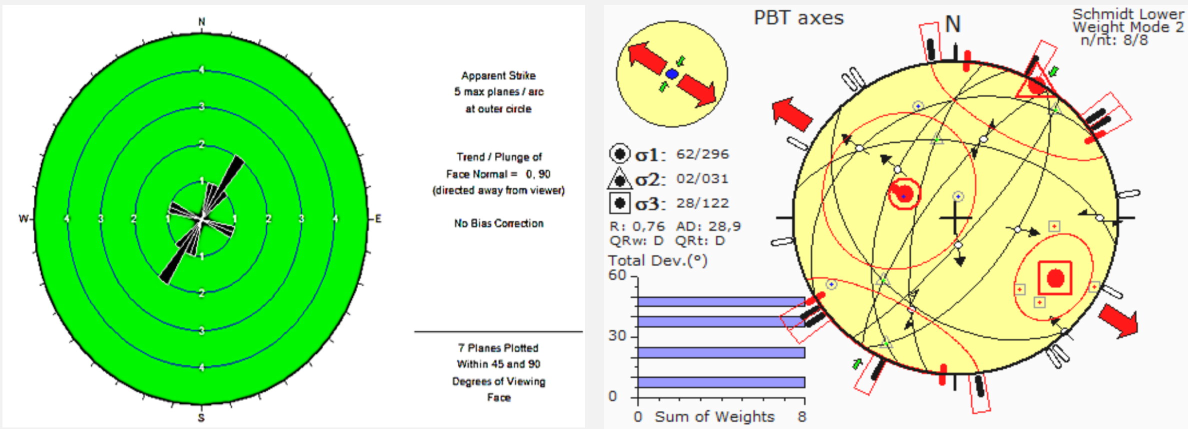
Schistosities

The schistosity measurement of the metamorphic rocks (Figure 3) in the locality of Mabuku shows different directions distributed in the four quadrants of the Schmidt grid (Table 1). The dips of these structures vary between 50° and 70°.

Figure 3. Schistosity planes on two outcrops of schist in the locality of Mabuku.

Table 1. Structural measures of rock schistosity

Latitude [UTM]	Longitude [UTM]	Altitude [m]	Strike [°]	Dip [°]	Azimuth [°]
38551	755788	1181	N115	70	N205
38504	756325	1329	N200	53	N290
38480	756300	1303	N190	70	N280
38276	755902	1201	N280	50	N010
36658	756592	1300	N034	60	N124
35444	756179	1343	N136	60	N226
34930	756458	1314	N239	29	N329



(a) (b)

Figure 4. (a) Preferred orientation of schistosity planes, and (b) Stress tensor of schistosity planes.

The schistosity planes of the locality of Mabuku are oriented almost NE-SW. The stresses at the origin of this schistosity are due to an extension movement of the sector (Figure 4a). The main stress (σ1) responsible for the schistosity of the study environment is oriented N296°/62°, the minimum stress (σ3) oriented N122°/28°, the intermediate stress oriented N031°/02° (Figure 4b).

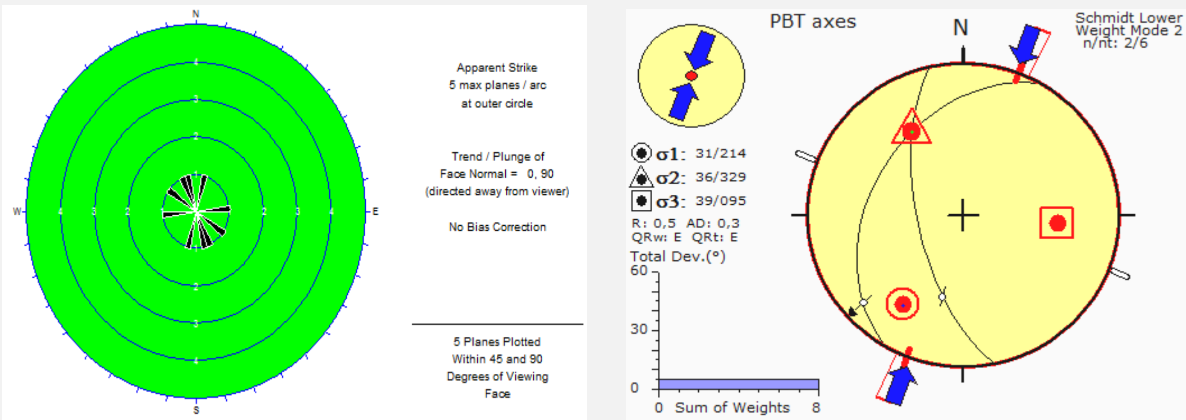
Fault planes

Measurement of the fault planes in the geological settings (Figure 5) in the locality of Mabuku shows very varied directions scattered in the four quadrants of the Schmidt grid (Table 2). Their dips are mostly between 58° and 75°.

Figure 5. Fault planes on two outcrops in the locality of Mabuku.

Table 2. Structural measurements of fault planes

Latitude [UTM]	Longitude [UTM]	Altitude [m]	Strike [°]	Dip [°]	Azimuth [°]
38468	756282	1282	N130	20	N220
36736	756655	1289	N040	70	N130
35608	755517	1373	N215	75	N305
35715	755772	1374	N260	62	N350
38560	757861	1510	N152	58	N242



(a) (b)

Figure 6. (a) Preferred orientation and poles of fault planes, and (b) Stress tensor of fault planes.

The fault planes are diversified with more concentrated poles in the fourth quadrant followed by the first quadrant where they are less numerous while in the second and third quadrant they are non-existent (Figure 6a). And, the regional stresses exerted on the rocks, and that caused faults are of the compressive type, with the main stress (σ1) oriented N214°/31°, the minimum stress (σ3) N095°/39°, and the intermediate stress being oriented N329°/36° (Figure 6b).

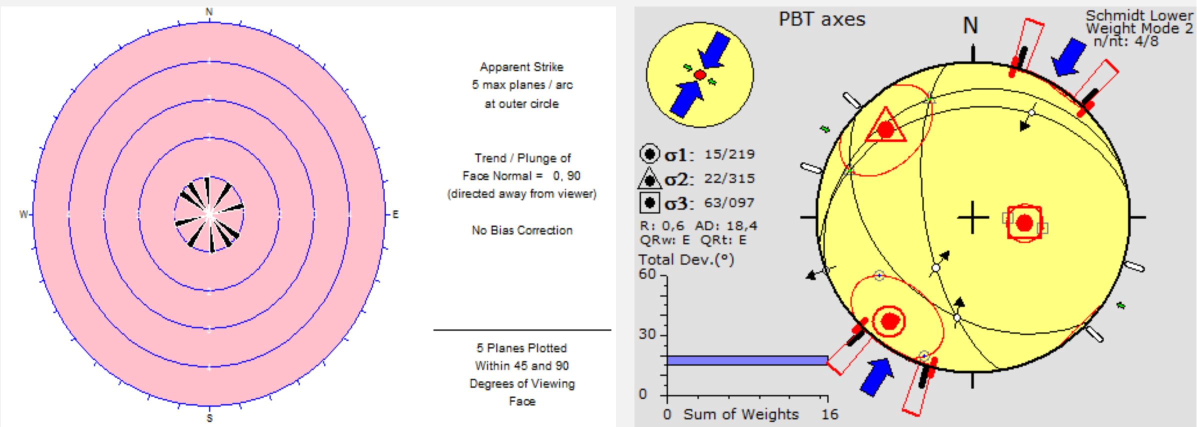
Veins

The measurement of filled fractures (veins) in the geological formations (Figure 7) of the Mabuku locality shows various directions distributed in all quadrants of the Schmidt grid (Table 3). Their dips vary for the most part between 50° and 80°.

Figure 7. Veins of quartz on two outcrops in the locality of Mabuku

Table 3. Structural measurements of vein planes

Latitude [UTM]	Longitude [UTM]	Altitude [m]	Steering [°]	¨Dip [°]	Azimuth [°]
38551	755788	1181	N045	70	N135
38276	755902	1201	N180	50	N270
38560	757861	1510	N079	58	N169
36736	756655	1289	N130	80	N220
35608	755517	1373	N355	75	N085



(a) (b)

Figure 8. (a) Preferred orientations and poles of veins, and (b) Stress tensor of vein planes.

The orientation of the veins is diversified with the majority of the poles in the first quadrant followed by the fourth and the two-remaining having each a pole (Figure 8a). The stresses responsible for the veins in the region are of the compressive type, with the main stress (σ1) oriented

N219°/15°, the minimum stress (σ3) oriented N097°/63°, and the intermediate stress oriented N329°/36° (Figure 8b).

DISCUSSION

The summation of all the deformations of the geological structures in the Mabuku locality can be summarized as follows (Figure 9). This shows that there are three preferential directions for the planar features in the study area. The NE-SW, NW-SE and WSW- ENE directions (Figure 9a on top). But also, the dips of these planes are mostly between 50° and 70° (Figure 9a at the bottom).

Furthermore, previous studies carried out in the study area show that the Precambrian basement has been affected by two successive tectogenesis (Vicat & Vellutini, 1987; Chorowicz et al., 1988; Clark, 1989; Boniface & Tsujimori, 2021; Odhipio et al., 2022). The Ruzizian folding (with two main directions of the fold axes: NW-SE and WNW-ESE); and the Urudian or Kibaran folding characterized by a NE-SW orientation (Lohest, 1946; Cahen, 1952; Safianikoff, 1952; Villeneuve, 1987; Rumvegeri, 1991; Prakash, 1993; François, 1995; Dewaele et al., 2016). In addition to these two, there is a third one, the Kibalian fold, which appears in northern Kivu, with two axial directions: WNW-ESE and WSW-ENE (Lepersonne, 1949; Lavreau & Ledent, 1975). Thus, looking at Figure 9a, the orientations of the structures in the Mabuku locality are similar to those of the Urundian or Kibaran and Kibalian folds.

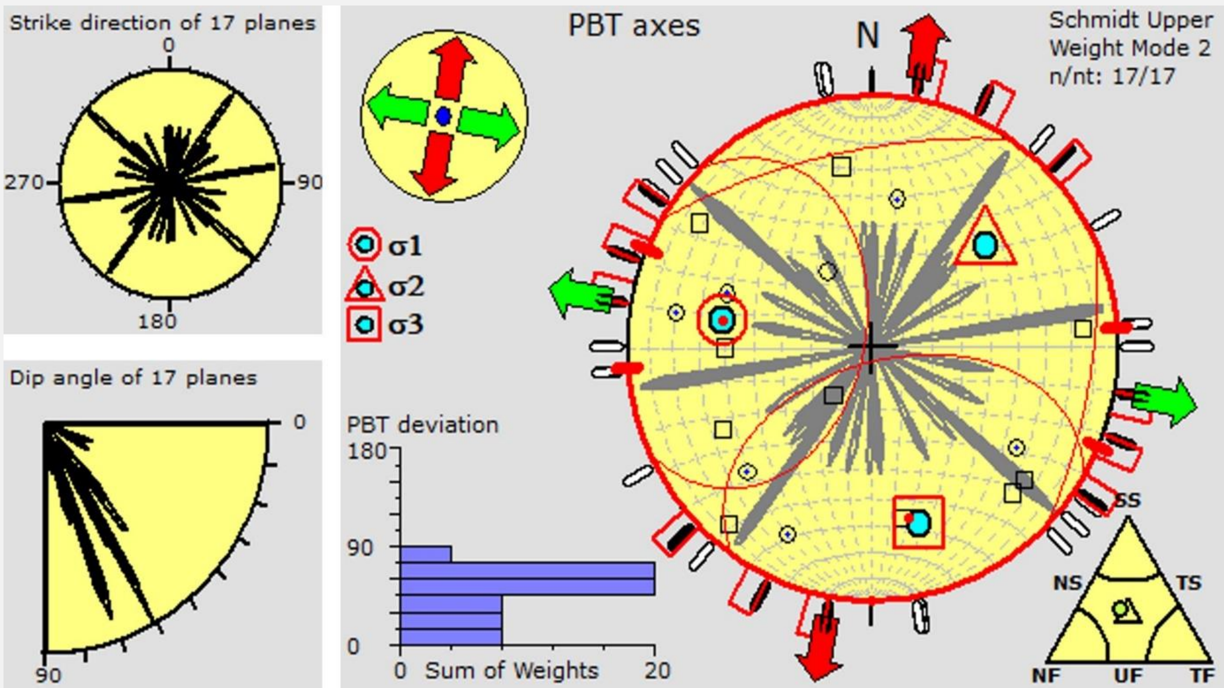


Figure 9. (a) Preferential orientation of structures in the locality of Mabuku, and (b) the main axes respectively of the principal stress σ1=38/100, the intermediate stress σ2=38/229, & the minimum stress σ3=29/345.

On the other hand, the geological survey carried out in the graben further north of Mabuku locality, in the Mungwalu (Nzebi) area, has highlighted the existence of a WSW-ENE oriented radial fault, whose presence is demonstrated by the abrupt interruption of the Sayo dolerite dyke, against the amphibolite (Woodtli, 1956; Delvaux & Barth, 2010). The direction of this fault coincides perfectly with one of the directions of the structures in the Mabuku locality.

In addition, the northern part of the Western Branch of the east African rift system (EARS) is well marked by the Albertine Rift (which includes the Albertine Graben, Semliki Basin and

Rwenzori Mountains) and the Kivu Rift (Ebinger, 1989; Lærdal & Talbot, 2002; Maier et al., 2008; Delvaux & Barth, 2010).

Based on the work of Simon et al. (2014) and Johnson (2014), detailed studies in the Albertine Rift for petroleum have revealed that rifting occurred in two phases. The first phase would have begun between the upper Oligocene and lower Miocene, followed by a short episode of compression during the mid-Miocene, which generated flower structures and anticlines; and the second phase of rifting occurred in the Pliocene, followed again by a short episode of compression during the Pleistocene. Our current research in the Mabuku locality, located in this region of rifting, shows an extensional regime (Figure 9b). This suggests a different tectonic regime than the one that caused generation of the rift.

In addition, the work of Delvaux & Barth (2010) in the East African Rift shows that the faults created by rift movement in the Albertine Rift are normal faults, and they result from a NW-SE extensional regime. This is similar to the tectonic regime in the Mabuku locality (extension along the NNE-SSW direction). However, the directions of this extension are not the same.

Furthermore, studies carried out in the Kivu rift, i.e. in the Virunga volcanic province, show that the rift faults are N-S oriented normal faults. These faults are generated by an extensional regime along the NW-SE direction(Delvaux & Barth, 2010). This result is almost identical to the extensional regime observed in the Mabuku locality, except for the orientation of the latter.

One of the consequences of the regional stresses on the geological setting in the study area is the transformation of the rocks on a regional level, sometimes followed by the appearance of schistosity on the pre-existing rocks (Chorowicz et al., 1988; Salpeteur et al., 1992; Simon et al., (2014); Bibentyo et al., 2015; Boniface & Tsujimori, 2021; Villeneuve et al., 2022). The schistosity planes of the Mabuku locality are almost NE-SW oriented exactly like the tectonics affecting the formations of the Urindi Group (Lohest, 1946; Cahen, 1952; Safianikoff, 1952). Thus, the stresses causing this schistosity are due to extensional movement of the area. The main stress (σ1) responsible for the schistosity of the study area is oriented N296°/62°, i.e. WNW-ESE, the minimal stress (σ3) is oriented N122°/28°, i.e. ESE-WNW, and the intermediate stress is oriented N031°/02°, i.e. ENE-WSW. This configuration shows a similarity with the Kibalian tectonics but also with the Ruzizi Group formations, taking into account the main stress (Safianikoff, 1952; Fernandez, 2015).

On the other hand, the other consequence of this tectonics is the fracture of the rocks on the regional level (Chorowicz et al., 1988; Clark, 1989; Ebinger, 1989; Rumvegeri, 1991; Salpeteur et al., 1992; Francois, 1995; Lærdal & Talbot, 2002; Lezzar et al., 2002; Delvaux & Barth, 2010; Simon et al., 2014; Dabo & Aïfa, 2013; Delvaux et al., 2017; Yantambwe & Cailteux, 2019). These different breaks followed a common preferential direction which contributed to the formation of the East African Rift (Villeneuve, 1987; Ebinger, 1989; Rumvegeri, 1991; Lærdal & Talbot, 2002; Lezzar et al., 2002; Delvaux & Barth, 2010; Simon et al., 2014; Dewaele et al., 2016; Delvaux et al., 2017). But most of these breaks have been filled by hydrothermal solutions during geological time forming veins(Salpeteur et al., 1992; Bibentyo et al., 2015; Dewaele et al., 2016). These veins have diverse orientations with the majority of the poles in the first frame of the Schmidt canvas followed by the fourth and the remaining two having one pole each. The stresses responsible for the veins in the region are of the compressive type, with the main stress (σ1) oriented N219°/15° or SW-NE, the minimum stress (σ3) oriented N097°/63° or ESE-WNW, and the intermediate stress oriented N329°/36° or NNW-SSE. These stress directions appear to be very different from the directions of the forces acting in the region. They are in fact the resultants of all these regional forces whose directions are indeed arbitrary.

CONCLUSION

We noted that in the locality of Mabuku, none filled faults were due to constraints of the compressive type, which are also similar to those affecting the formations of the group of Ruzizi. The schistosity of these rocks was due to a very different tectonic regime, extension. The strange characteristics of the Schistosities of metamorphic rocks in the locality of Mabuku (strikes, dips, and tectonic regime) link them to those of the Kibarian formations (Urundi group). As for the veins, they were generated by a force of the compressive type. The direction of this constraint, responsible for the creation of veins, is different from that of the faults and the schistosities. And it is identical to those that affected the Kibalian formations. Briefly, there is a combined influence of the Ruzizian, Kibarian and Kibalian tectonics. As the future extends of this works, it will be very important to describe and to analyze microscopically the rocks which outcrop in the locality of Mabuku. And also, to perform geochemical analysis for highlighting the presence of chemicals such as tin, copper, gold and Colombo-tantalite.

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