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Geothermal Characterization Of Kibalian Formations Of The Ruwenzori Sector In The Democratic Republic Of The Congo

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ABSTRACT

This research was carried out in the area surrounding the thermal springs of Mutsora, Masambo and Kambo, in the Ruwenzori sector, Eastern D. R. Congo. It was conducted in order to characterize geothermal resources of the area by studying the geology and geochemistry of rocks around the thermal springs as well as by identifying some surface manifestations. Another aspect of the study was the determination of orientation of the maximum stress on the rock formations of the area in order to discover whether or not the resources are of structural control. Geological and geochemical investigations of rocks samples were done respectively using petrographical microscope and X-Ray Fluorescence. Results revealed that the study area is dominated by schists at Mutsora and Kambo, and quartzites at Masambo. Geothermal surface manifestations are greatly represented by hot and warm springs. The reservoirs at Mutsora, Masambo, and Kambo are fault hosted geothermal systems in extensional terrain. The principal heat source is high heat flow and high geothermal gradient ascribed to crustal extensional and thinning. Geothermal resources are controlled by structures including cracks and fractures in the field. The study area has got many cracks due its active seismicity and its proximity to the local active volcanoes.

1. Introduction

The Ruwenzori sector is a geographical area located in Beni territory, North Kivu Province in the eastern part of the Democratic Republic of the Congo (Figure 1). The area is geologically part of the western branch of the East African Rift System within the Kibalian formations. It is bounded on the East by the Ruwenzori massifs; to the west by the Nyavakele, then the Lubamwami flows; in the North a conventional boundary separates the Ruwenzori sector from the Watalinga chiefdom (Figure 1). In the South the sector is limited by the Lubirihya flow up to Lake Edward, and the Semuliki River at its confluence with the Munghalika flow. It has a surface area of 2,359 km². Its general altimetry ranges from 1175 to 5119 meters above sea level at the Marguerite peak (Noel, 1981). Its hydrography is dominated by the Semuliki River that connects Lake Edward to Lake Albert. The geologic formations in this area are of various ages and have experienced major tectonic phenomena that have led to

several orogenies and rifting. Geothermal phenomena, seismicity and volcanism are also recognized.
This research aims at studying the geological and geochemical features of rocks surrounding hot springs of the area. The specific objectives of the research are to identify the lithology around hot springs of the Ruwenzori sector, to identify surface geothermal manifestations and to determine the orientation of the maximum stress of the sector as well as the orientation of the formations. At the end we would like to propose the control of the geothermal activity and to increase the degree of knowledge of geothermal resources in the Ruwenzori sector.

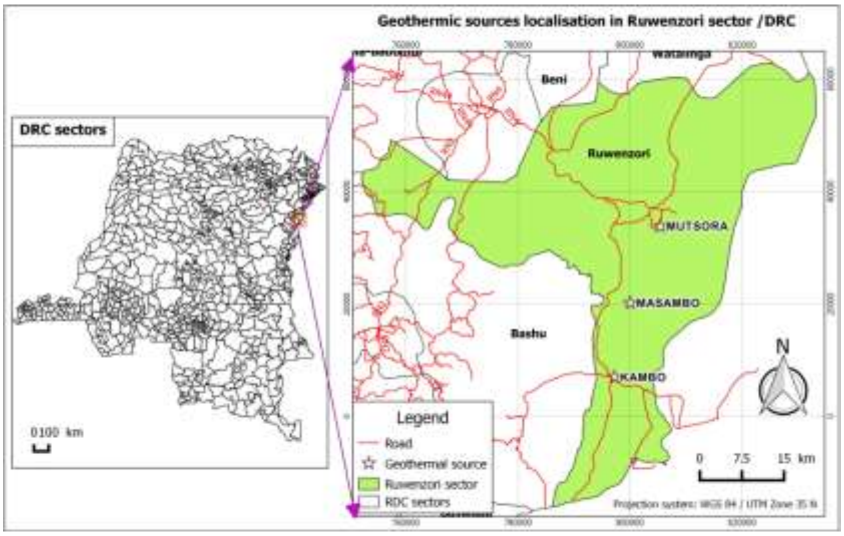

Figure 1: Map showing geothermal springs in the Ruwenzori sector, DRC

2. Literature Review

Several authors have studied the geology of the study area (Cahen, 1954; Debelmas, 2008; Passau et al., 1935; Lavreau and Ledent, 1975; Lepersonne, 1968; Noel, 1981; Michot, 1937, 1938; Tanner, 1970, 1971, 1973). These are mostly Belgian colonial exploration missions with mining objectives. The most recent data are unpublished undergraduate research reports.
The East African Rift, whose manifestations began about 30 million years ago, is controlled by the internal heat of the earth. It consists of aborted rifts, active rifts and rifts under formation (Paul, 2009). It therefore includes several hot spots like the Afar (Vincent, 2009). It's constantly animated by earthquakes and volcanism (Geoffrey, 2009). It is characterized by a recent tertiary magmatic extension and it includes a volcanism associated with geothermal activity (Wohletz and Heiken, 1992) whose studies have concluded that the geothermal potential of the East African Rift is above 15,000 MW (Björn, 2017). Ahmed (2009) quantified geothermal energy into very low geothermal energy (at temperatures <30°C), low geothermal energy (between 30 and 90°C), medium geothermal energy (between 90 and 150°C) and high geothermal energy (between 150 and 350°C). Moreover, Subtavewung et al. (2005) gave another classification of hot springs based on their surface temperature. The geothermal reservoir types are characterized as hydrothermal reservoir, hot dry rock reservoirs, geopressured reservoirs and magma energy (Anderson and Lund, 1997).
The African rift undergoes various extension stress directions in some places. The stress are generally oriented NW-SE in the Kivu rift (Delvaux and Barth, 2009; Delvaux et al., 2012.).
The East of the DR Congo has a lot of hot springs which are actually potential for geothermal energy but it has remained less known. Some of these geothermal resources in the DR Congo are controlled by structural cracks and fissures and the area is located within the rift valley

(Faulds et al., 2009). Almost every geothermal exploration starts by the identification of surface manifestations if they are available and seen at the surface like thermal springs (Ochieng, 2014). But this not the rules as some resources are found in particular areas without any surface manifestation.

The study area undergoes the rifting phenomena of the East African Rift since the Cenozoic. Geologically, it includes formations of several ages: the Burundian or Karagwe-Ankole, the Kibalian or Buganda-Toro system (Uganda) and the Crystallophyllian complex or West-Nile complex or Basement complex. The Kibalian facies are hard to differentiate. As a result, the following connections are important in the Ruwenzori sector: Stanley volcanic formations or Luhule-Mobisio Basic Complex: lower to middle Burundian; high peaks schist group: upper Kibalian and, probably, the sedimentary base of Luhule-Mobisio (Lower Burundian); Kilembe schist group: Lower Kibalian (Noel, 1981).

3. Methodology

3.1. Field work

The field was carried out in late May and early June 2018. It consisted of field visits to the various sites of hot springs in the Ruwenzori sector. The geographical coordinates were taken with the Global Positionning System (G.P.S.)-etrex10 (precision: 3 meters) in Universal Transverse Mercator format (U.T.M.) format. The direction of flow and structural studies were taken by using the Sylva compass. Temperature was measured in-situ using a thermometer, while the pH was roughly estimated using indicator paper. Rock samples were collected with the hammer and described previously, then labeled. Surface water samples were also collected in the field. Cracks in the formations were observed and, were interpreted using the Right Hand Rule. Magnetism was estimated on the ground using a magnetic pen. A 0.1N dilute hydrochloric acid allowed checking for calcite-rich formations. At each sampling site two rock samples and one bottled water sample were taken for laboratory analysis.

3.2. Analytical work, data processing and data interpretation

Chemical analysis was done between June and July 2017. For water samples, physical parameters including electric conductivity (*Ec*) was measured at the laboratory of the Congolese Office for Control (*O.C.C.* in French) in Butembo. It allowed determining the Total Dissolved Solids (*T.D.S.*) by the formula $T.D.S. = K \times Ec$, where K is a constant varying from 0.55 to 0.8; and Ec the conductivity. In general, K = 0.7 for mineral water. The conductivity measurement was done by using a conductivity meter.

As far as chemical analysis is concerned, the water samples were sent to Nairobi and the results are still to come; water chemistry is therefore not being discussed at this stage.

As for the rock samples, geochemical and petrographical analyses were conducted in Kenya at the Ministry of Mines and Petroleum in Nairobi. The rock samples of Mutsora, Masambo and Kambo were respectively captioned by M1, M2, MS1, MS2, K1 and K2. All samples were subjected to geochemical analysis using X-Ray Fluorescence method. However M1, MS1 and K1 samples were also subjected to petrographical analysis using Nikon Eclipse LV100POL optical microscope. The geochemical results (Table 5) were processed using WinRock software for the ternary diagram (Figure 2). The structural data were interpreted using Dips and Win tensor software to uncover the structural orientation and major tectonic stress of the study area. The QGis 2.8.9 software was used to make the map of the study area.

4. Results

4.1. Data presentation

4.1.1. *Mutsora thermal spring*

The thermal spring of Mutsora lies at the U.T.M. coordinates of 0805369 E, 0033852 N and Altitude 1119 m. The maximum surface temperature is 43°C and pH is 6. The direction of flow at the source is from N163 to N343. The thermal water discharges from the depths through cracks within the rocks. These cracks on the rocks have preferentially oriented plans N176/30 and N184/30. Other structural measurements (Table 1 and 2) were taken in the vicinity of the thermal spring. The rock is fine-grained with a blackish color. It reveals superimposed benches separated by reddish colorations. It shows no magnetism when tested with a magnetic pen. The rock formations in the vicinity show schistosity.

Table 1: Structural data of schistosity plans

N°	Easting	Northing	Altitude (m)	Direction	Pendage	Dip direction
01	0809200	0044044	1467	196	60	286
				200	70	290
02	0809141	0045824	1422	102	80	192
				116	76	206
				126	74	216
				198	36	288
				200	60	290
3	0807667	0037447	1421	80	20	170
4	0808418	0037452	1453	114	16	204
5	0808510	0037636	1457	138	42	228
				138	40	228
6	0808727	0037652	1462	18	48	108
				20	34	110
				334	50	64

Table 2: Diorite crack plans

N°	Easting	Northing	Altitude (m)	Direction	Pendage	Dip direction
01	0808163	0036004	1400	54	30	144
				34	80	124
				14	76	104
				170	80	260
				260	84	350
				34	88	124
				294	86	24

4.1.2. *Masambo thermal spring*

The hot spring of Masambo is located at the U.T.M. coordinates 0800007 E, 0020173 N and altitude 1032 m. The spring releases steam. The pH is 5. The maximum surface temperature is 52°C. The flow direction is from N117 to N297. The rock is micro granular with quartz minerals. It presents blackish traces with the presence of feldspars. It does not react with hydrochloric acid and is non-magnetic. The structure is massive (unoriented). The rock is a quartzite. Water ascends from the depths though fractures whose dips and dip directions are given in table 3.

Table 3: Cracks in the rock at Masambo

N°	Easting	Northing	Altitude (m)	Direction	Pendage	Dip direction
01	0800007	0020173	1032	128	60	218
				115	58	205
				308	33	38
				260	28	350
				112	70	202
				135	30	225
				140	60	230
				306	50	36
				296	36	26
				38	70	128
				32	48	122
				326	44	56
				276	78	6

4.1.3. The thermal springs of Kambo

The Kambo hot (warm) spring is located at the U.T.M. coordinates of 0797154 E, 0006949 N and Altitude 1020 m. The pH is 6. The maximum surface temperature is 37°C. Flow direction is from N84 to 264. The water discharges like bubbling in a mud (mud pools/pots) from the depths. At 2 meters from the source, rock formations are similar to quartzites and schists.

4.2. Analysis and interpretation of the data

4.2.1. Rock geochemistry

The major elements contents of rock samples are given in Table 4. As mentioned, it was done using X-Ray Fluorescence. Major elements interpretation allowed confirming the rock names given from the petrography classification diagrams. By the classification diagrams (ternary diagrams), it was possible to determine the rock series using their chemical composition.

Table 4 : Major composition of rocks samples as by in weight %

Sample	K1	K2	M1	M2	MS1	MS2
SiO_2	86.996	82.118	64.383	9.644	76.664	71.96
Al_2O_3	6.252	15.788	18.02	2.762	13.923	15.19
K2O	1.087	0.59	3.953	0.084	6.431	9.628
Na_2O	0.99	2.41	5.89	1.167	5.892	12.907
TiO_2	0.239	0.052	0.55	0.078	0.058	0.02
CaO	0.1	0.79	0.463	33.6	0.439	0.419
MgO	1.52	0.01	5.807	25.231	1.612	1.987
MnO	0.024	0.008	0.058	0.274	0.02	0.006
FeOt	3.542	0.297	6.35	1.1	0.435	0.199
P_2O_5	0.096	0.152	0.152	0.42	0.061	0.262

Samples K1, K2, M1, MS1 and MS2 have huge concentration of SiO_2 whereas sample M2 has less concentration. M2 is actually a limestone and its CaO concentration is much higher than for other samples. K1 was identified to be a metamorphic rock belonging to the schist classification. K2 was identified to be a sericite schist. However, MS1 is a quartzite. And the respective chemical composition confirms the rocknames.

AFM diagram classification

AFM (Al_2O_3 - FeO – MgO) diagram classification of rock samples from the field (Figure 2) helped to classify and distinguish the rock environments into two series. A represents The tholeiitic series and B representts the magmatic Calc-Alkaline Series. As seen in this ternary diagrams all rock samples from the study area are distributed in the calc alkaline series. The diagram was done using WinRock diagram. The farthest sample (sample M2) is normally a limestone, which is not supposed to be in this diagram as it's a sedimentary rock.
Mg and **Fe** have a geochemical affinity for mantle and metamorphic formations and **Al** is concentrated in several primary formations, in clay sedimentary rocks and in mica of metamorphic rocks.
This AFM diagram classifies the field in a metamorphic gradient of medium pressure-high temperature.

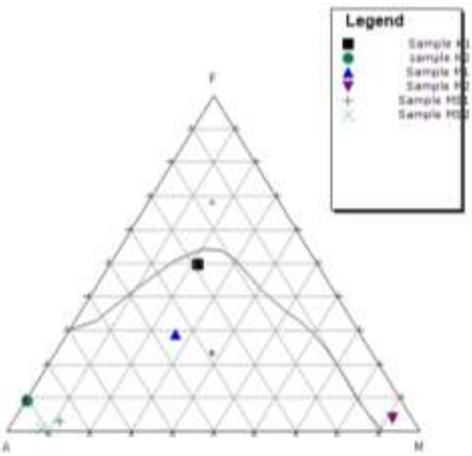

Figure 2: AFM diagram classification of tocks samples

4.2.2. <u>Petrographical study</u>

Sample MS1

Macroscopic description. Hand sample is a coarse grained rock rich in quartz, micas (biotite and muscovite) and plagioclase.

Microsocopic description
Under plane polarized light plagioclase are seen through their cleavage. The zoning of biotite is also important to notice. Under crossed polars (left photographs of figure 3) lamellar twinning is visible for plagioclases and micas (biotite and muscovite). The pleochroism of biotite is also visible and goes brown to green in color. The violet mineral is a ferromagnasian mineral and it was identified as a biotite too.The rock is actually a quartzite.

Figure 3: Photographs of thin sections as taken under plane polarized (left photo) and under crossed polar (righter photo). Magnification x10

Sample M1

Macroscopic desciption. Hand sample is a fine grained rock dark green in color. It has some oxidation haloes. It has got pyrite, sericite and also some quartz. The rock is characterized by its shistosity.

Microscopic description. Under plane polarized light (Figure 4, righter photograph), it has pyrite minerals which are greatly visible in the crossed polarized light. Sericite is colorless. Under crossed polars, the sericite minerals are also present and seen as small grain and its charcateristic pleochroism. The twinning of some grains is interpreted as the presence of biotite within the thin section.

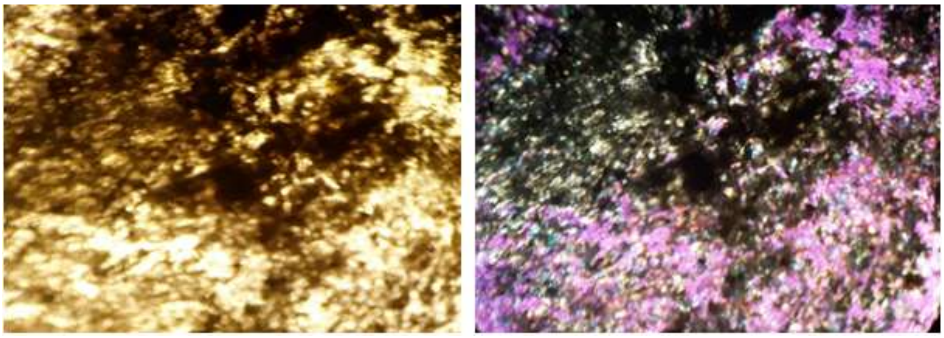

Figure 4: Photographs of thin sections as taken under plane polarized (lefter photo) and under crossed polar (righter photo). Magnification X10

Sample K1

Macrosocopic desciption. Hand sample is fine grained and rich in quartz, ferromagnesian minerals, pyrite and a little of mica. This rock is also a schist as it is characterized by schistosity.

Microscopic description. Under plane polarized and crossed polars, the white minerals are quartz and a bit purple minerals are micas (Figure 5). Ferromagnesian minerals are the blackish minerals.

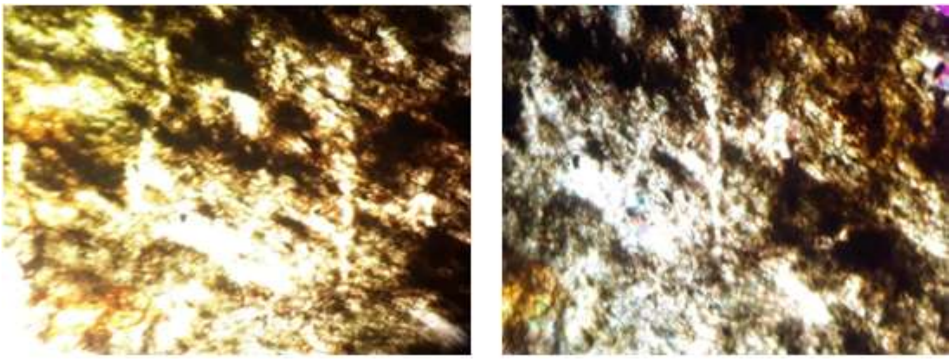

Figure 5: Photographs of thin sections as taken under plane polarized (lefter photo) and under crossed polars (righter photo). Magnification X10

4.2.3. <u>Structural studies</u>

The rock cracks stress

The maximum stress σ1 is oriented N69/77, the average stress σ2 is oriented N274/12 and the stress σ3 is oriented N183/5 (Figure 6). These 3 constraints exert on the ground extensive movements in the NNE-SSW plan. The breaks have two major planes of fractures. With regard to the circle of Morh opposite, the ground is favorable to the brittle deformations.

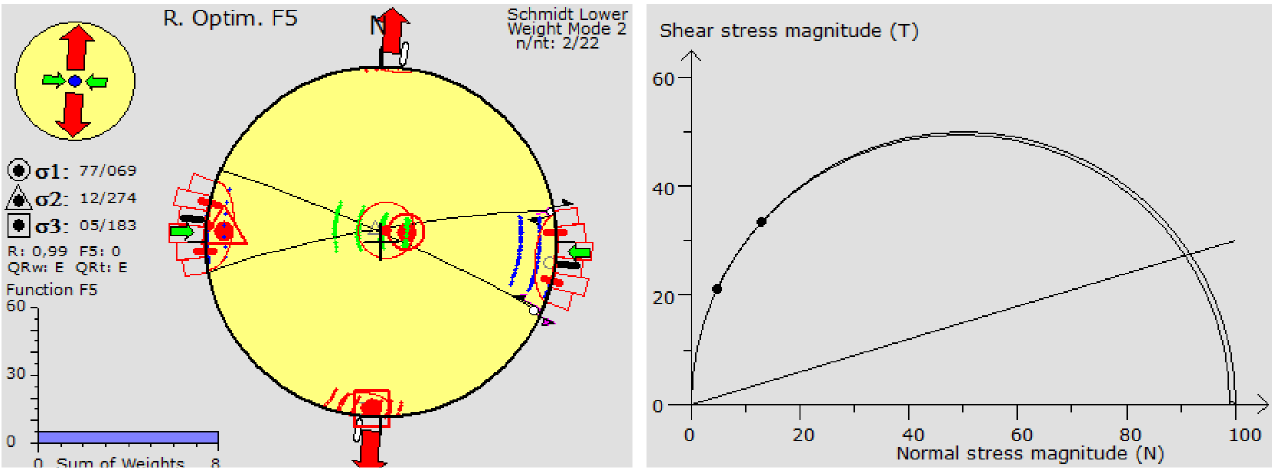

Figure 6: Stress (lefter photo) and Mohr diagram (righter photo) of the rock breaks

The stress of schistosity

The maximum stress σ1 is oriented N264/34, the average stress σ2 is oriented N132/45 and the stress σ3 is oriented N13/26 (Figure 7). These 3 constraints exert on the ground extensive movements in the NNW-SSE plane. The schistosity presents a major plane of fracture. With regard to the circle of Mohr opposite, the ground is favorable to the brittle deformations.
With such a small dip at σ3, it's possible that the field would have overlapped at the σ3 position.

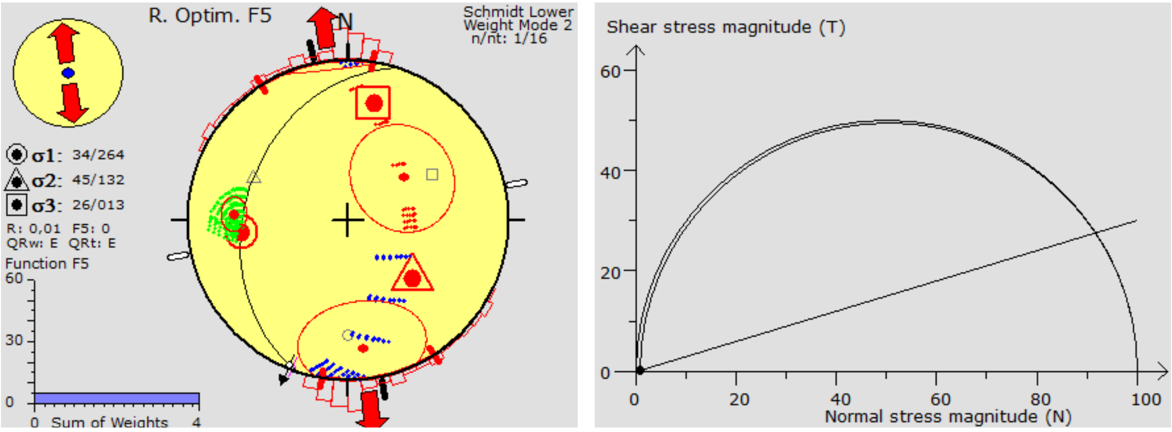

Figure 7: Stress (left photo) and Morh diagram (right photo) of the schistosity

The direction of schistosity

The breaks are preferably oriented NE-SW and NW-SE (Figure 8). The schistosity is preferably oriented NNE-SSW.

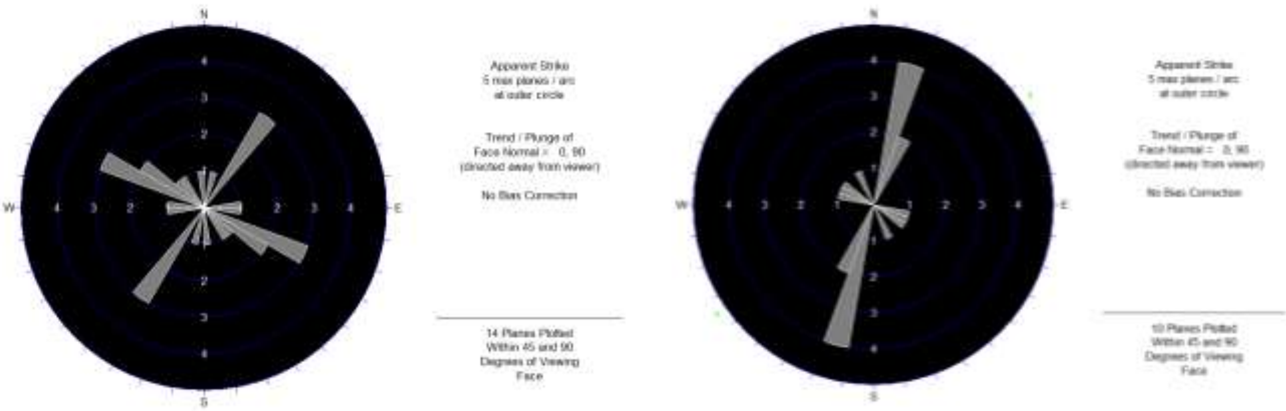

Figure 8: Direction of breaks (left photo) and schistosity (right photo).

5. Discussion

This study which was done on the petrography and geochemistry of geothermal areas of Mutsora, Kambo and Masambo allowed determining the features of rocks surrounding the hot springs. All rock samples from the study area are distributed in the calc-alkaline series in the ternary diagram, this means that the field has got too much concentrations of alkaline minerals which include K and Na. The chemical composition of rocks is also a fact that confirms the rocknames that were given during the petrographical analysis.

Some of the surface geothermal manifestations include hot springs, hydrothermal alteration and cracks from which hot water is flowing (Ochieng, 2014; Wohletz and Heiken, 1992). The presence of structural cracks explain well that the geothermal field in the sector of Ruwenzori is highly controlled by structures in the rock formations and this explains well how water travels in and from beneath the crust through those cracks (Faulds et al., 2009). Volcanism is seldom in the area but its location within the rift valley and its average distance from Nyiragongo and Nyamulagira active volcanoes in North Kivu make sense of the presence of these geothermal potentials (Wohletz and Heiken, 1992). The average surface temperature of

hot springs in Mutsora, Masambo and Kambo being respectively 43°C, 57°C, and 37°C, they can be classified on that basis as following: Mutsora and Kambo belong to the thermal springs; whereas the Masambo hot spring belongs to the hyperthermal springs (Subtavewung et al., 2005). According to Ahmed (2009), the Ruwenzori thermal springs are about low geothermal energy.
The thermal springs of Mutsora and Kambo discharge occur in schists. The spring of Masambo discharges in quartzites. Reservoir of Mutsora, Kambo and Masambo are fault hosted geothermal systems in extensional terrain. The principal heat source is the high heat flow and high geothermal gradient ascribed to crustal extension and thinning. The direction of the major stress has been found with NE-SW and NW-SE oriented breaks and NNE-SSW oriented schistosity. In the Kivu rift, this orientation is generally NW-SE (Delvaux and Barth, 2009; Delvaux et al., 2012.).With respect to the Morh circles, the terrain is favorable for rock cracks. Geothermal energy thus takes on structural control in the Ruwenzori sector. The exploitation of geothermal energy in the Ruwenzori sector of D.R.C. could be useful for greenhouses, horticulture, pisciculture, swimming pools, and space heating.

6. Conclusion and Recommendations

Masambo, Kambo and Mutsora have geothermal resources as it is evidenced by geothermal surface manifestations such as hot and warm springs. Geothermal resources are controlled by structures like cracks and fissures which are extended and multiplied by the intense and active seismicity of the area which is located within the western branch of the Albertine rift and not too far from active volcanoes of Nyiragongo and Nyamulagira in the South. Rocks in these area are metamorphic (schists, quartzite) except some sedimentary rocks like limestone. Geologic formations are affected by metamorphism. Surface manifestations in the study area include warm and thermal springs.
It is recommended that further investigations for geothermal potentials should be done using further methods and these include the soil gas survey, shallow temperature survey and geophysical survey (MT/TEM and gravity).

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