Environmental and Earth Sciences Research Journal
Vol. 10, No. 1, March, 2023, pp. 26-32
Journal homepage: http://iieta.org/journals/eesrj

Geochemistry and Structural Inputs of the Mineralized Quartz Veins from Imonga Mining Area, Maniema, DR Congo: General Overview

Sicke Lunkomo[1,2], Mupenge M. Parfait[2*]

[1] Department of Geology, Université du Moyen Lualaba, Kalima 136, Lualaba, DR Congo
[2] Department of Geology, Université Libre de Grands Lacs, Bukavu 132, DR Congo

Corresponding Author Email: parfaitmupenge@gmail.com

https://doi.org/10.18280/eesrj.100104

Received: 15 February 2023
Accepted: 10 March 2023

Keywords:
quartz veins, gold, geochemistry, structural, Imonga, Eastern DR Congo

ABSTRACT

The quartz veins in the Imonga region are confined to the primary ENE-WSW trend, which is quite consistent with the Kibara metasediments. The objective of this work was to study the topographic, structural and geochemical features of the mineralized quartz veins in the Imonga area. Field investigations have shown that the area is composed of seristoschists and quartzites, with seristoschists more abundant than quartzite. Mineralized quartz veins found with sericite schist have different compositions between quartz, iron oxide ± sericite and mafic minerals. Mineralized quartz veins contain 0.50 to 3.44 ppm Au, while quartz veins that are considered sterile contain less than 0.50 ppm Au. Since the concentration correlates with Au in samples with moderate Au content, Au exhibits a positive correlation with only Mo while it is negatively correlated with other metals such as Cu, Pb, Zn and Co. The studied ridges show signs of multiphase strain and it is associated with D2 strain in the region. The presence of quartz veins in the shear zone suggests that the site of gold mineralization is epigenetic. The main type of weathering includes sericitization. The general directional trend of Imonga quartz veins can be exploited for future geological exploration.

1. GENERAL BACKGROUND AND LOCAL GEOLOGY

Veins are prevalent rock features that indicate fluid flow in fracture networks [1]. During their formation, veins provide information on tension, strain, pressure, temperature, fluid origin, and fluid composition. Gold lodes and skarn mineralisation are two common instances [2]. Because there is plenty of fluid flow and open area for ore minerals to deposit, hydrofracture breccias are classic candidates for ore exploration. Quartz vein systems in regions that have undergone deformation are still the main deposits of primary Au [3]. Deformation in these regions is gradual, and the movement of hot fluid (hydrothermal) from underground into the resulting structure also follows the deformation process. These fluids eventually deposit substances into these structures, forming veins and veins with different [3, 4]. The veins in these areas show different patterns including error-filling veins, enlarged veins, and stockwork-style veins. Gold-bearing veins are usually of the multi-needle type with different texture features. Some of these textures are commonly associated with mineralized regions (mineralized veins) while others are found in barren regions [5, 6]. Some of the mineralized textures include overprinted and modified textures, including Phantom Vein, Ribbon and Breccia Quartz, Laminated Quartz, and Comb Quartz textures [5]. Gold-bearing quartz veins are connected to metamorphic rocks with a variety of compositions, including those with quartz and gold as well as those with quartz and gold as well as sulfide, iron oxide, sericite, and mafic minerals [7].

The Imonga region lies 130 kilometers northeast of Kasongo and 210 kilometers southeast of Kindu, the Maniema province's capital. The Mesoproterozoic Karagwe Ankole belt, which also includes the Kibara belt in Central Africa, contains the province of Maniema [8]. This structure stretches from the Democratic Republic of the Congo's (DR Congo) southern Katanga province to Uganda's western region. A Palaeoproterozoic basement rise that represents the NW extension of the Ubende belt over Lake Tanganyika separates the two belts (SW Tanzania). A bimodal magmatism is present in the Kibaran chain [9-11]. The Kibaran has been claimed to have two cycles of fundamental magmatism: intercalary tholeiitic magmas in the Bugarama metasediments, and oceanic tholeiites in the Nya-Ngezi Group [10]. Four primary acidic magmatic groups invaded the Kibaran formations during acid magmatism [9], [12-14]. The Kibara of Kivu and Maniema are highlighted by tin group metal mineralization and gold mineralization, both of which are connected to G4 [9] and/or Gr5 granites [8]. Some gold discoveries, nevertheless, are unrelated to the G4 granite. Instead, they have metamorphogenic origins [15]. Moreover, authors [16] argue that the link between gold concentrations and the G4 granite is speculative and extremely doubtful. At the moment, most research is focused on gold and metals associated with stratiform basic intrusions, such as nickel, cobalt, copper, and the platinoid group, as well as possibly titanium, vanadium, and iron. Furthermore, the chain appears to be rich in industrial minerals (andalusite, feldspar, kaolin, muscovite, quartz, talc, and wollastonite). Finally, there are metals associated with sedimentary exhalation deposits [15]. Although the Kibara chain data were studied on a vast scale without paying attention to certain very little but crucial features, they were used to depict the geology of the entire region. The historical map that was amended after Dekun (1959) and the information that is currently available on the study area demonstrate that the Imonga area's local geology is defined by two majors geological lithologies, including schists and dolerite intrusions (Figure 1). The other data on the study area shown that, the Imonga-Saramabila area consists of Mesoproterozoic metasedimentary and metavolcanic rocks, belonging to the Kivu Supergroup [17]. The typical mineralization is gold, which is extracted from colluvium materials or can be found hosted by quartz veins cut through schists and dolerite geological formations in the area. Despite the existence of artisanal gold mining activities in the area, the Imonga sector has never been the object of a study contributing to the stuctural and geochemical control of the veins intersecting the geological formations of the area [18]. This would help later on in the investigations of mining prospections. This work is part of the framework to bring the first data on the structural and geochemical characteristics of the quartz veins in the selected area. The findings result for this research describe the characteristic of quartz veins within the Imonga area, the structural inputs and the geochemical composition of some selected veins samples. All these parameters have been compared to the finding results of other areas in the region. This paper is subdivided into five parties, the introduction presents the general background, while the second part is focused to describe the technic and materials that have been used to carry out this investigation. The third part is focused on the findings results and discussions with the comparison made with other results found in the general region. The fourth part is summarizing the conclusion to the research and the fifth and last part is presenting the references used to hand up this present paper.

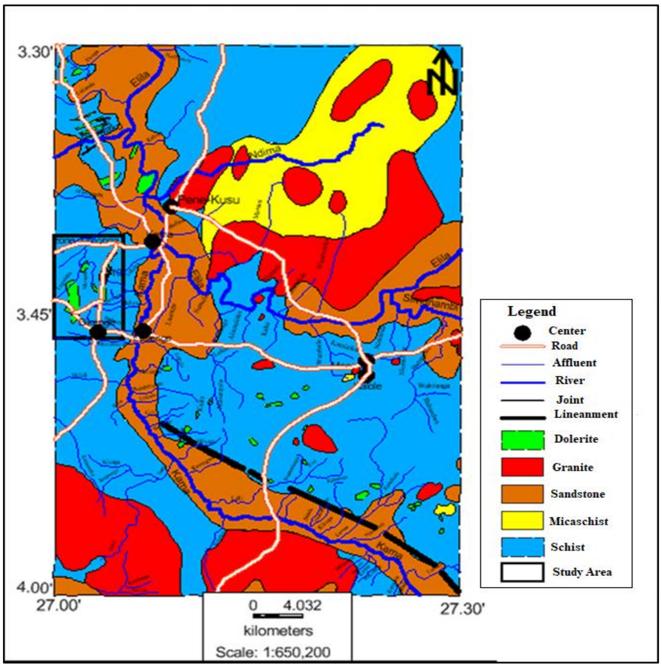

Figure 1. Geological map of the zone depicting the local geology of the Imonga area [18]

2. METHODOLOGY

Details description of various geological lithologies was completed using a variety of geological field materials, Compass clinometers were used to take in-situ measurements of the main quartz veins' strikes and dips for structural analysis. This will later aid in determining the overall orientation trend of the quartz veins, which has been compared to the orientation of all fractures in the region. During structural and lithological mapping of the study area, quartz veins were collected as grab samples with a geological hammer. All sampling points' geographic coordinates were determined using a Garmin global positioning system. Thin section slides of gold-bearing quartz veins were prepared and examined under a petrological microscope. Ten (10) quartz veins samples were crushed, sieved, and pulverized with hardened steel, and permitted to pass through 75 m. Following that, the concentrations of major oxides and trace elements were determined using two wave length dispersive X-ray fluorescence spectrometers (PW 1480 and PW 2400) and the inductively coupled plasma mass spectroscopy (ICP-MS) method. To achieve near total digestion, the samples were first decomposed with HCL, HNO3, HCLO4, and HF acids. Authors [19] describe the procedure used. The quartz veins samples were then analyzed for gold using fire assay and instrumental neutron activation analysis (INNA) to determine the concentration of gold traced to international reference standards, as documented by the research [20].

3. RESULTS AND DISCUSSIONS GENERAL CHARACTERISTIC AND GEOCHEMISTRY

The hydrothermal quartz veins in the meta-sediments are generally of multi-centimeter thickness, with some being macro veins with large thickness in Figure 2 (a-c) and others having small thickness in Figure 2 (d-f). Some quartz veins have angular fragments that have disaggregated (breeched) in Figure 2 (h) and Figure 2 (i) and are composed of quartz and potassium feldspars in Figure 2 (h), other quartz veins are found associated with small conjugated joins in Figure (2g). The majority of micro veins within the study area correlated with the shear zone in Figure 3 (c) and Figure 3 (d), indicating epigenetic emplacement. The size of these fragments ranges from 2 mm to 1 cm. They are composed of silica, muscovite, and iron hydroxide (Goethite) deposited within quartz fragments. These quartz veins are more common in seristoschists. The microscopic studies revealed that quartz is most abundant mineral in these veins found in Imonga area, Sericite is dispatched within the veins, and goethite is displaying moderate abundance with a small quantity of muscovite and felsic minerals (Figure 3 (a) and Figure 3 (b)).

The geochemical composition of quartz veins is shown in Table 1. In mineralized veins, the concentration of Si_2O ranges from 64.54 to 75.62wt%, Ti_2O from 0.005 to 0.3wt%, Al_2O_3 from 1.91 to 9.92wt%, Fe_2O_3 from 1.36 to 15.16wt%, MnO from 0.001 to 0.25wt%, P_2O_5 from 0.007 to 0.46wt%, K_2O from 0.37 to 0.255wt%, Na_2O from 0.03 to 0.12wt%, CaO from 0.002 to 0.12wt%, MgO from 0.07 to 0.36wt%. With the exception of Al_2O_3, Fe_2O_3, and K_2O, which have higher concentrations, the majority of the key elements in the examined quartz veins had concentrations less than 1 weight percent. These veins do, however, contain a lot of silica. The quartz veins are hence very siliceous and shown the positive correlation between SiO_2 versus Al_2O_3, MgO, Na_2O and K_2O in figure which indicate the enrichment of these elements during the evolution.

The quartz veins that were tested can be split into two groups: the mineralized veins, which contain Au between 0.05 and 3.44ppm, and the barren quartz veins, which contain less than 0.5ppm Au. Only 3 of the examined samples had low levels. The low Au concentration in the barren quartz veins indicates that gold mineralization is not distributed evenly throughout the area. Other trace element concentrations in mineralized veins include Zn, Ni, Sr, Pb, Co, Cd, V, Cu, Mo, and Cr, which range from 29 to 172ppm, 14-80ppm, 15.3-304ppm, 11-120ppm, 2-37ppm, 2-12ppm, 29-200ppm, 16.1-220ppm, and 1-86ppm, respectively. Li and Sn concentrations are nearly identical in both mineralized and barren quartz veins, with average values of 12.5 and 12.3, respectively. The concentration of as in quartz veins is very high, ranging from 75ppm to 2110ppm, and it is worth noting that high as concentration correlates with Au in samples with moderate Au concentration. Au has a positive correlation with only Mo and a negative correlation with other metals like Cu, Pb, Zn, and Co in Figure 4 which can indicate the probable existing of a polymetallic deposit within the area that implicate the much careful investigations in the future.

4. DISCUSSION

Quartz veins host gold in many gold fields [21, 22], and this is the case with the Imonga gold prospect. The cross-cutting interactions between the mineralized quartz veins indicated several stages of vein emplacement in the region. The epigenetic style of mineralization is also indicated by the fact that the mineralized quartz veins cut through the nearby semioticists. The poles to quartz veins plotted on the stereographic projection and rose diagrams of the quartz veins show that in the Imonga area, the veins present many families in Figure 5 (a) with the preferential dip trending to the South in Figure 5 (b). The last family shown the general orientation trend ENE-WSW in Figure 5 (c) which is quite concordant with Kibara metasediments (NE-SW), secant to the pegmatite veins in Manono- Kahungwe sector which trend N40°E N50° [23] and perpendicular to the NW-SW trending shear zone that relates to the Paleoproterozoic Ruzizian chain which controls the mineralization of the Namoya gold deposit in Maniema [24]. The ENE-WSW trend being the dominating ones for the veins and thus gold mineralization within the Imonga prospect is structurally controlled. The presence of the quartz vein in the study area's shear zone is proof that the quartz was formed through epigenetic processes. Massive quartz veins are generated over the course of numerous episodes of vein opening, fluid interaction, and vein sealing events, whereas brecciated quartz veins are the consequence of modification of previously formed veins and indicate a later event [25]. Massive and brecciated quartz in the area differ in texture and composition, indicating that they were created during various hydrothermal episodes. According to the study [26], breccias are indicators of brittle deformation and have been considered typical to be of shallowly-formed veins because the majority of mineralized quartz veins are brecciated [27]. Hydro-fracturing (fluids assisted fracturing) is likely to have been the process that led to the formation of the breccias and was triggered by variations in fluid pressure. This could also be seen in the Imonga quartz veins and it suggests that the quartz veins were likely generated in association with brittle deformation at shallow depths.

5. CONCLUSION

Au-bearing quartz veins are restricted to significant ENE-WSW orientations in the Imonga region, which are in agreement with the Kibara metasediments and close to the shear zone that governs mineralization at the Namoya gold deposit. These veins have fractures that are both partially and fully filled. As a result, this represents the dominant mineralization style in the region. The investigated quartz veins were produced as a result of various hydrothermal processes and are primarily made up of quartz, a small amount of sericite, and goethite, which are iron oxides. Brecciaed veins are likely the result of hydro fracturing, which is the technique that caused their creation. The examined veins exhibit signs of multiphase deformation, as shown by the interactions between veins that are cross-cutting, mineralogical, and textural. The similarity in the generalized strike directions of the host rocks and quartz veins suggests that the emplacement of the quartz veins was caused by D2 deformation. It predates local fracturing and metamorphism. This structural setting revealed quartz vein evidence in the research area's shear zone, indicating that the location of gold mineralization was epigenetic. Any further exploration work to uncover the potential mineralization in the Imonga area should consider detailed structural studies that have been omitted in previous studies but actually mentioned in this paper. This research provides and enlight the structural inputs data and orientation of the Imonga veins adding with the characteristic of the veins within the Imonga area with the little description concerning the host rock type and mineral compositions of these veins which have not been mentioned in previous studies. However, the data on the evolution system of the fluid that leads to the formation of these veins haven't been mentioned in this paper, even the age the mineralization is not described. Thus, to complete this study, future researches should be focused on the fluid inclusion analysis to precise the evolution of the fluid in the system during to the formation of this veins, a developed aspect on geochronology should be done to determinate the age of both the host rock and the mineralization.

Table 1. Geochemical composition of the investigated quartz veins

Sample No	975538	975539	975544	975545	975546	975547	975548	975559	975576	975577
SiO_2	67.19	75.41	68.23	75.62	74.59	75.62	74.71	74.10	64.59	71.40
TiO_2	0.05	0.05	0.13	0.12	0.10	0.12	0.05	0.10	0.30	0.10
Al_2O_3	1.91	3.97	5.25	8.75	8.61	8.50	3.10	5.86	9.92	4.85
Fe_2O_3	13.60	15.16	4.29	3.58	5.51	3.69	1.36	7.16	10.22	3.75
MgO	0.12	0.18	0.07	0.08	0.32	0.36	0.07	0.32	0.25	0.22
MnO	0.23	0.06	0.05	0.00	0.01	0.02	0.01	0.25	0.02	0.18
CaO	0.05	0.10	0.07	0.10	0.05	0.12	0.02	0.02	0.07	0.02
K_2O	0.48	0.95	0.43	0.66	2.23	2.55	0.37	1.93	1.24	1.46
Na_2O	0.03	0.05	0.04	0.05	0.08	0.09	0.04	0.12	0.05	0.11
P_2O_5	0.14	0.46	0.23	0.32	0.23	0.44	0.07	0.07	0.27	0.07
TOT	83.79	96.39	78.80	89.29	91.73	91.52	79.81	89.93	86.95	82.16

As	440	2110	840	740	1120	620	220	75	900	460
Ba	300	660	1120	1540	1260	2690	480	1280	560	660
Be	0.5	3.9	1.3	1.8	1.8	1.3	<0.5	<0.5	<0.5	<0.5
Cd	2	12	4	4	6	3	<1	<1	4	2
Co	37	31	4	2	<1	<1	3	24	9	<1
Cr	17	36	19	19	42	45	17	27	33	33
Ni	55	55	52	80	28	24	19	25	75	14
Sn	11	14	<10	<10	<10	<10	<10	<10	<10	<10
Sr	15.3	130	118	157	138	340	38.1	16.4	53.3	40.7
V	29	142	66	78	199	200	42	153	115	110
Y	7.7	29.3	15.3	21.6	20.1	32.5	5.9	5.6	23.8	18.2
Zr	17.5	26.1	9.3	11.1	42.7	50.4	10.1	39.7	38.3	71.5
Au	0.02	1.53	0.62	1.09	1.71	1.12	3.44	1.63	0.01	0.35
Ag	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu	130	220	91.1	69.8	141	90.7	37.5	16.1	200	88.9
Mo	5	86	22	20	30	21	8	1	14	8
Pb	220	134	37	73	50	39	24	11	99	25
Zn	172	135	41	58	32	29	30	44	115	29

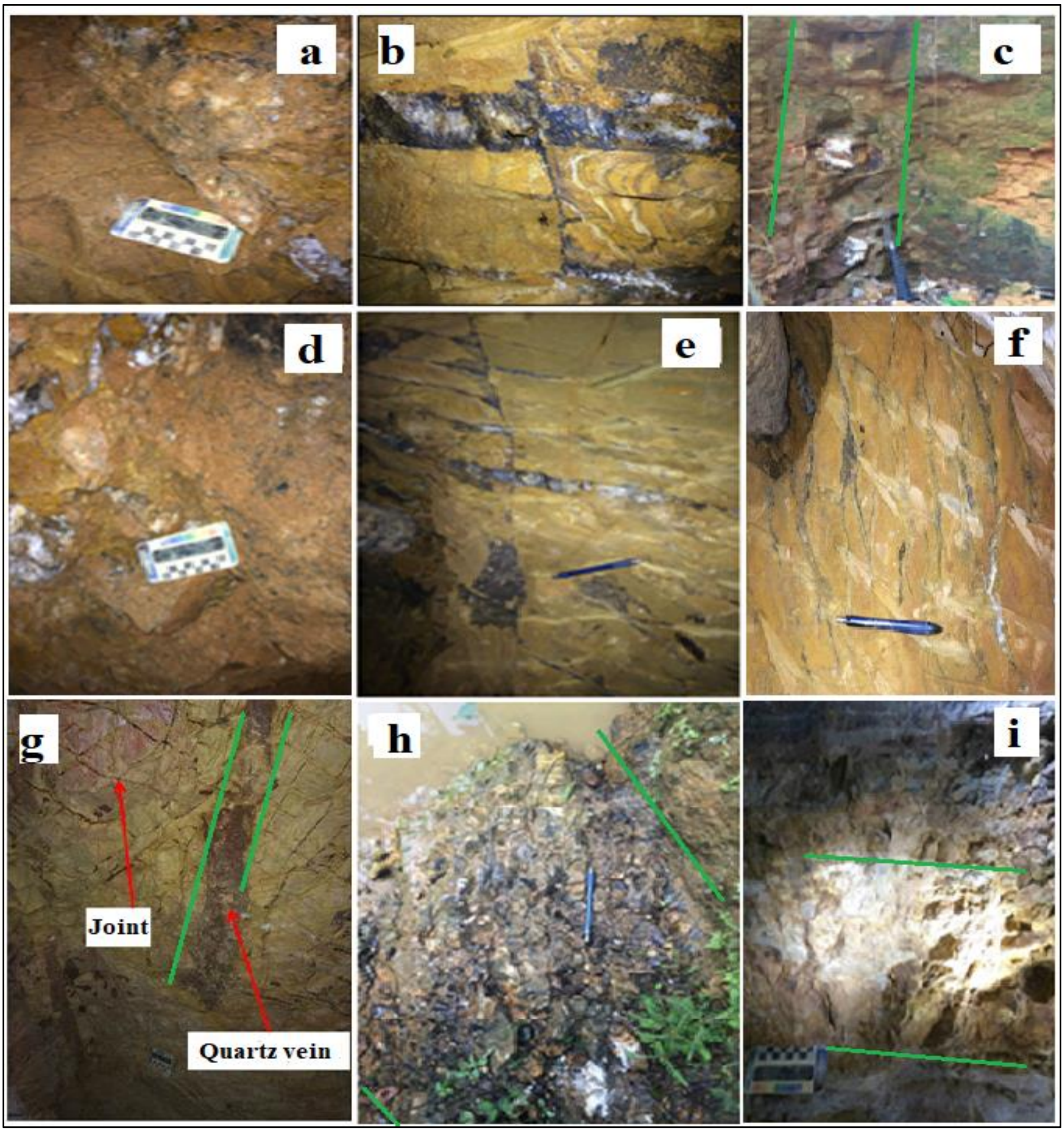

Figure 2. Massive quartz macro veins (a,b,c), multiple conjugated micro quartz veins (d,e,f), quartz vein which joint affecting the sericitoschists (g) and brecciated quartz in the area (h, i)

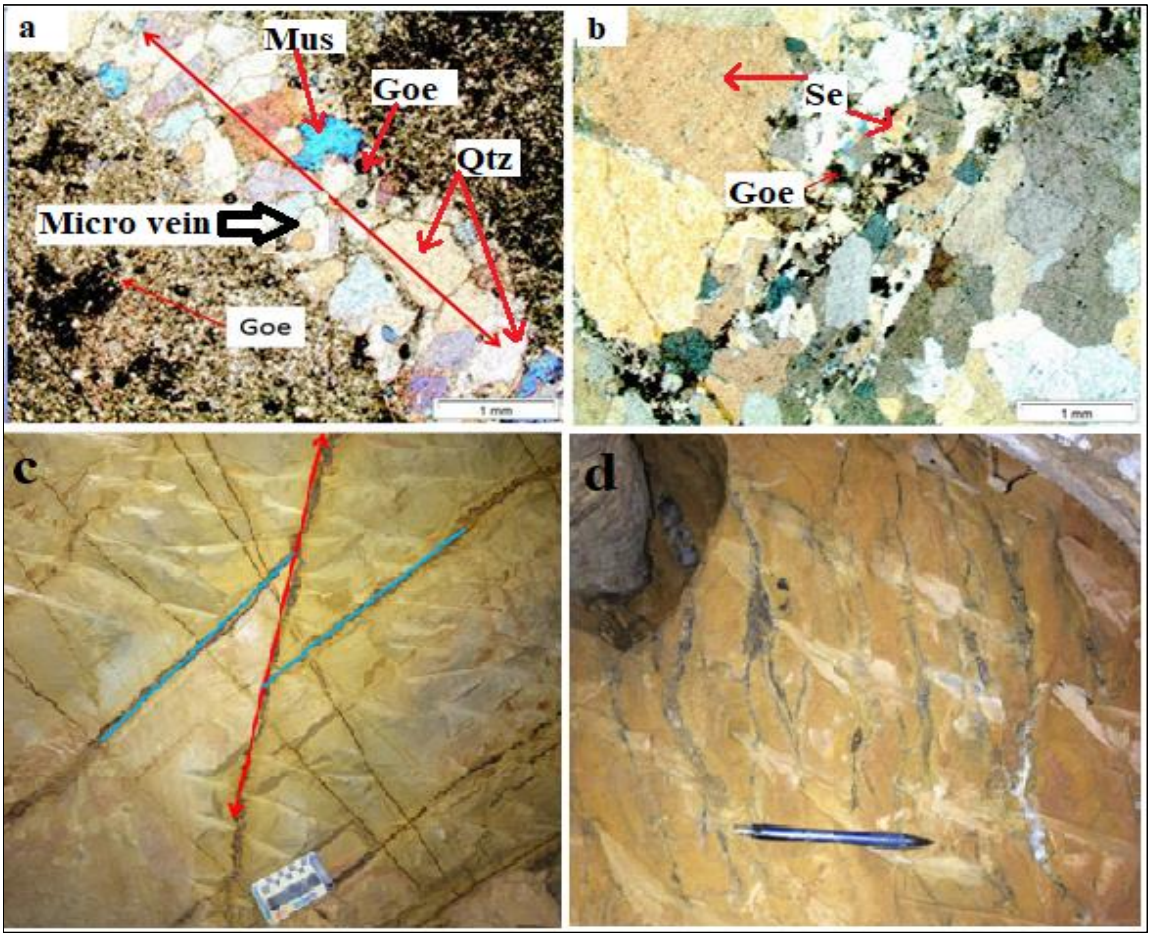

Figure 3. (a,b) Microphotograph of quartz veins showing the mineral assemblages composed of Quartz (Qtz), Goethite (Goe), Sericite (Se), and Muscovite (Mus), and (c,d) quartz micro veins occur in shear zone

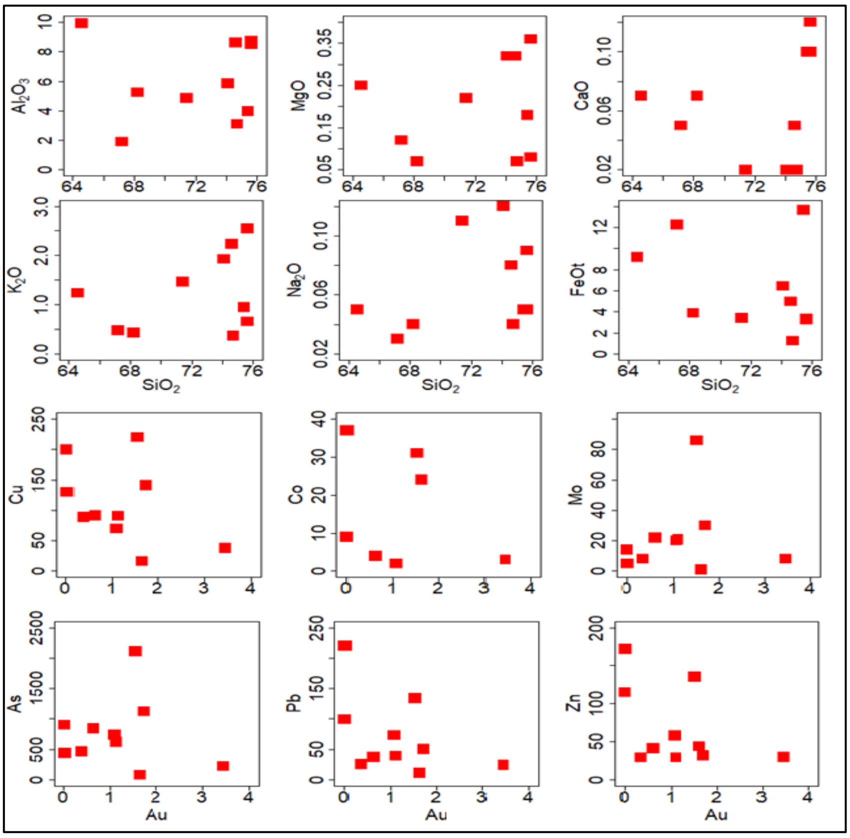

Figure 4. SiO_2 versus major elements and Au versus some selected trace elements variation diagrams for the investigated quartz veins

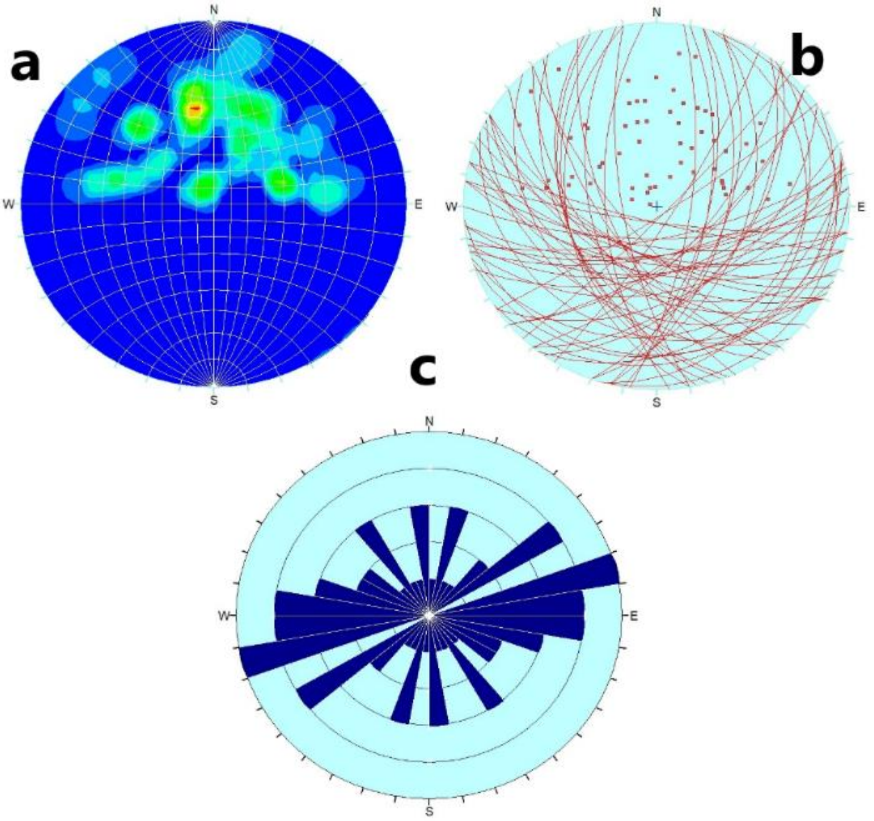

Figure 5. Stereonets showing various families of the investigated veins (a), preferential Dip (b) and general orientation trend (c)

6. CONFLICT OF INTERESTS

The authors affirm that the publishing of this paper does not involve any conflicts of interest.

REFERENCES

[1] John, M.F. (1994). A historical review of metamorphic fluid flow. Journal of Geophysical Research: Solid Earth. https://doi.org/10.1029/94JB01147

[2] Bons, P.D., Elburg, M.A., Gomez-Rivas, E. (2012). A review of the formation of tectonic veins and their microstructures. Journal of Structural Geology, 43: 33-62. https://doi.org/10.1016/j.jsg.2012.07.005

[3] Mero, Y. (2015). Quartz veins characteristics and Au mineralization within the Batouri Au District, East Cameroon. Science Research, 3(4): 137-149. https://doi:10.11648/j.sr.20150304.12

[4] Simard, M., Bedoin, G., Bernard, J., Hupé, A. (2006). Metallogeny of the Mont-de-L'Aigle IOCG deposit, Gaspé Peninsula, Québec, Canada. Mineralium Deposita 41(6): 607-636. http://dx.doi.org/10.1007/s00126-006-0061-y

[5] Kreuzer, O.P. (2006). Textures, paragenesis and wall rock alteration of lode Au deposits in the Charter Towers district, North Queensland: implication for the conditions of ore formation. Mineralium Deposita, 40(6): 639-663. http://dx.doi.org/10.1007/s00126-005-0010-1

[6] Junks, A.J., Cooke, D.R. (2007). Geological and structural controls on Au mineralization in the Tanami district Northern Territory. Mineralium Deposita, 42(1): 107-126. http://dx.doi.org/10.1007/s00126-006-0097-z

[7] Nforba, M.T., Chi, S.J., Emmanuel, T.T., Kouske, A.P. (2020). Structural and geochemical characterization of gold mineralized quartz veins in Belikombone Gold Prospect, Betare-oya Gold District, East Cameroon. Engineering Science, 5(2): 17-26. http://dx.doi.org/10.11648/j.es.20200502.12

[8] Tack, L. Tack, M., Wingate, B., De Waele, J., Meert, E., Belousova, B., Griffin, A., Tahon, Fernandez-Alonso, L. (2010) The 1375 Ma "Kibaran event" in Central Africa: Prominent emplacement of bimodal magmatism under extensional regime. Precambrian Research, 180 (1-2): 63-84. https://doi.org/10.1016/j.precamres.2010.02.022

[9] Cahen, L., Snelling, N.J. (1984). The geochronology and evolution of Africa. Science, 226(4680): 1309-1310. https://doi.org/10.1126/science.226.4680.1309

[10] Rumvegeri, B.T. (1987). Le Précambrien de l'Ouest du lac Kivu (Zaïre) et sa place dans l'évolution géodynamique de l'Afrique centrale et orientale. Pétrologie et Tectonique. Thèse de doctorat ès Sci. Université de Lubumbashi. http://refhub.elsevier.com/S0024-4937(20)30238-3/rf0255, accessed on Jan, 12, 2023.

[11] Fernanadez-Alonso, M., Cutten, H., De Waele, B., Tack, L., Tahon, A., Baudet, D., Barritt, S.D. (2012). The Mesoproterozoic Karagwe-Ankole Belt (formerly the NE Kibara belt): The result of the prolonged extensional intracratonic basin development punctuated by two short-lived far -field compressional events. Precambrian Research, 216–219: 63-86. https://doi.org/10.1016/j.precamres.2012.06.007

[12] Fernandez-Alonso, M., Lavreau, J., Klerkx, J. (1986) Geochemistry and geochronology of the Kibaran granites in Burundi, Central Africa: Implications for the Kibaran

orogeny. Chemical Geology, 57(1-2): 217-234. https://doi.org/10.1016/0009-2541(86)90104-X

[13] Pohl, W. (1987). Structural control of tin and tungsten mineralization in Rwanda, Africa. Berg. Und Huttenmannische Monatshefte (Ver. Mit Montan Rundschou), 122 (2a): 59- 63.

[14] Kanzira, H. (1989). Classification magmato-tectonique des granites du Rwanda. - IGCP n° 255 newsletters.

[15] Pohl, W.T. (1992). Metallogenie de la Chaine Kibarienne Afrique Centrale. de Newsletter, Bulletin, 4(1992).

[16] Günther, M.A., Dulski, P., Lavreau, J., Lehmann, B., Möller, P., Pohl, W.L. (1989). The Kibara tin -granites: Hydrothermal alteration versus plate tectonic setting, IGCP 255. Newsletter 2: 21-27. http://refhub.elsevier.com/S0024-4937(20)30238-3/rf0140, accessed on Jan. 2, 2023.

[17] Fernandez-Alonso, M., Kampata, D., Mupande, J.F., Dewaele, S., Laghmouch, M., Baudet, D., Lahogue, P., Badosa, T., Kalenga, H., Onya, F., Mawaya, P., Mwanza, B., Mashagiro, H., Kanda-Nkula, V., Luamba, M., Mpoyi, J., Decrée, S., Lambert, A. (2015). Carte Géologique de la République Démocratique du Congo au 1/2.500.000: Notice explicative. République Démocratique du Congo, Ministère des Mines.

[18] De Kun, N. (1960). Les gisements de cassitérite et de columbo-tantalite du Nord Lugulu, Kivu, Congo belge. Annales de la Société géologique de Belgique, 82: 1959-1960.

[19] Wallance, J., Boiron, M.C., Catheline, M., Verlet, M., Marignac, C. (2004). The granitic hosted Au deposit of Moulin de Chéni (Saint Yrieix district, Massif Central France): petrography, structural, fluid inclusion and oxygen isotope constraints. Mineralium Deposita, 39: 265-281. https://doi:10.1007/s00126-003-0396-6

[20] Klein, E.L., Alves dos Santos, R., Fuzikawa, K., Angelica, R.S. (2001). Hydrothermal fluid evolution and structural control of the Guarim Au mineralization, Tapajos Province, Amazonian craton, Brazil. Mineralium Deposita 36: 149-164. http://dx.doi.org/10.1007/s001260050295

[21] Suh, C.E. (2008). Sulphide microchemistry and hydrothermal fluid inclusion in quartz veins Batouri gold district (Southern Cameroon). Journal of the Cameroon Academy of Science, 8(1): 19-29. https://www.ajol.info/index.php/jcas/article/view/87036, accessed on Dec. 12, 2022.

[22] Pitfield, P.E.J., Campbell, D.G. (1996). Significance for gold exploration and structural styles of auriferous deposits in the Archean Bulawoyo-Bubi greenstone belt of Zimbabwe. Transaction Institution of Mining and Metallurgy, Section B, Applied Earth science, 105: 4152.

[23] Dewaele, S., Hulsbosch, N., Cryns, Y., Boyce, A., Burgess, R., Muchez, P. (2015). Geological setting and timing of the world-class Sn, Nb-Ta and Li mineralization of Manono-Kitotolo (Katanga, Democratic Republic of Congo). Ore Geology Reviews 72(1): 373-390. http://dx.doi.org/10.1016/j.oregeorev.2015.07.004

[24] Twangiza Exploration French Annual Report. (2013). https://www.sec.gov/Archives/edgar/data/1286597/000091228206000402/banro6k_twanziga-techrpt.htm, accessed on Jan. 3, 2023.

[25] Wagner, T., Boyce, A.J., Erzinger, J. (2010). Fluid-rock interaction during formation of metamorphic quartz veins: a REE and stable isotope study from the Rhenish Massif, Germany. American Journal of Science, 310(7): 645-682. https://doi.10.2475/07.2010.04

[26] Craw, D., Windle, S.J., Angus, P.V. (1999). Gold mineralization without quartz veins in a ductile - brittle shear zone, Macraes Mine, Otago Schist, New Zealand. Mineralium Deposita, 34: 382-394.

[27] Chauvet, A. (2019). Structural control of ore deposits: The role of pre-existing structures on the formation of mineralized vein systems. Minerals, 9 (1): 56. https://doi.org/10.3390/min9010056