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ARTICLE

Study on Epithermal Gold Mineralization System at Shwebontha Prospect, Monywa Copper-Gold Ore Field, Central Myanmar

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ABSTRACT

The Shwebontha prospect area is situated in the Central Volcanic Belt, central Myanmar, where the well-known Sagaing Fault serves as its eastern boundary. This study aims to document key the mineralogy, host rock geochemistry and ore mineralizing fluids. The mineralization, hosted by Upper Oligocene to Middle Miocene rhyolites, displays a strong lithological control. Mineralization is characterized by gold-bearing silicified massive ore and chalcedonic quartz veins in which sulfides are clustered and disseminated not only in quartz gangue but also in rhyolite host rocks. The significant ore minerals in the mineralized veins include pyrite, sphalerite, galena, chalcopyrite, and gold. Common hydrothermal alterations such as silicic, argillic and propylitic alteration types are recognized. According to the fluid inclusion data and interpretation, ore mineralizing fluids in the research area are characterized by formation temperatures of 260-280 °C and salinity of 0.35-2.41 % wt. NaCl eq. respectively. Mixing of hydrothermal fluids was generally considered to be an effective mechanism for ore transport and deposition.

Keywords: Geochemistry; Alteration; Fluid inclusions; Ore mineralization; Central Volcanic Belt; Shwebontha

1. Introduction

The Monywa copper-gold ore field is one of the largest endowed areas in entire Southeast Asia. It is located within the western part of the well-known

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Sagaing Fault in the Central Volcanic Belt, Central Myanmar (**Figure 1**) [1-3]. The field hosts four distinct high sulfidation copper ore deposits including Letpadaung taung, Kyisintaung, Sebataung, Sebetaung South and other small gold prospects Kyaukmyet, Shwebontha, Taungzone, Myeik respectively. The Shwebontha prospect is located about one kilometre ENE of the Letpadaung taung Cu-Au deposit in which operating mining [3]. Tectonically, this research area is a part of Central Volcanic Belt (**Figure 1**), which is one of the prominent geological aspects and multistage metallogeny in Myanmar. Generally, the belt hosts several porphyry-related skarn deposits and epithermal gold-copper deposits, epithermal gold-silver deposits, base metal deposits and mesothermal gold deposits. Mineral exploration especially targeting precious and base metal deposits in the research area, Monywa copper-gold ore field was carried out by Ivan Hold Copper Company Limited in 1995. Based on a resource estimate by Htet [4] (unpublished data), the maximum gold grade contains 3 g/t to 10.4 g/t. In addition, the concentration of base metals containing Cu (12.45 ppm), Pb (105.43 ppm), Zn (392.96 ppm), As (115.92 ppm), and Sb (5.299 ppm) in the drill core analysis [4] (unpublished data). This paper aims to document the geological, alteration, and mineralization characteristics of the Shwebontha prospect, Monywa copper-gold ore field, one of the well-known epithermal deposits in the Monywa copper-gold ore field. This presents a description of the associated host rocks and hydrothermal alteration mineral assemblages, the ore mineral assemblages, mineralization characteristics and the characteristics and ore-forming processes of the hydrothermal system. This research also reveals the conceptual model for the development of the epithermal system in the Shwebontha prospect, Monywa copper-gold ore field.

2. Geological background and setting

Myanmar lies in a tectonic setting covering several metallogenic belts, with a high prospective for the occurrence of economic gold-copper deposits. Several ore deposits have been generated as world-class mines in the last decades [5,6]. In general, there are numerous metallogenic belts in Myanmar that have great potential for economic gold and copper mineralization, tin-tungsten and lead zinc silver deposit (**Figure 1**). These many metallogenic belts were formed during specific metallogenic epochs during the Phanerozoic [7] and related to long-lived subduction that formed during Late Mesozoic and Cenozoic [8,9]. Most of the copper and gold deposits are occurred within the Central Volcanic Belt (CVB) also known as Wuntho Popa Magmatic Arc (WPMA) at the western portion of the renowned Sagaing Fault [10] (**Figure 1**) in Myanmar and are concentrated in the Monywa copper-gold ore field, Kyaukpahto, and Wuntho-Massif regions. Accordingly, the major Sagaing Fault [11] is still an energetic, deep-seated, N-S trending, right-lateral strike-slip fault, which extends over 1500 km across the country (**Figure 1**). As a result of this structural constraint, the right-lateral strike-slip fault is considered to be critical geologic control of the ore mineralization in the Central Volcanic Belt.

According to the geological background, the Central Volcanic Belt is recognized by the presence of Mesozoic age intrusive and volcanic rocks and Cretaceous-Pliocene sedimentary formations. Meanwhile, the Central Volcanic Belt is composed mainly of Upper Cretaceous to Tertiary granodioritic intrusive rocks, and with a minor part of volcanic rocks of Upper Cretaceous to Quaternary ages [1,5,9]. The Monywa copper-gold ore field is located in the Central Volcanic Belt, within the middle portion of Myanmar [1,5,8] (**Figure 1**). In the Monywa copper-gold ore field, Mesozoic volcanic rocks are mainly intruded by the Upper Cretaceous age of granodiorites [1]. Based on the previous research [1,2,4] the Monywa copper-gold ore field of high-sulfidation (HS) copper-gold deposit and low-sulfidation (LS) gold-silver deposit and base metal deposits in the Monywa copper-gold ore field are intimately related to basement rocks and granitic intrusions. Generally, the basement rocks are extensively distributed by volcanic rocks such as andesite, quartz andesite porphyry, dacite, and rhyolite in the Magyigon Formation (**Figure 2**). Most copper-gold (high-sulfidation type) and gold-silver (low-sulfidation type) and base metal deposits between the Chindwin River and Powintaung are mainly formed by the Upper Oligocene to Middle Miocene Magyigon Formation (**Figure 2**).

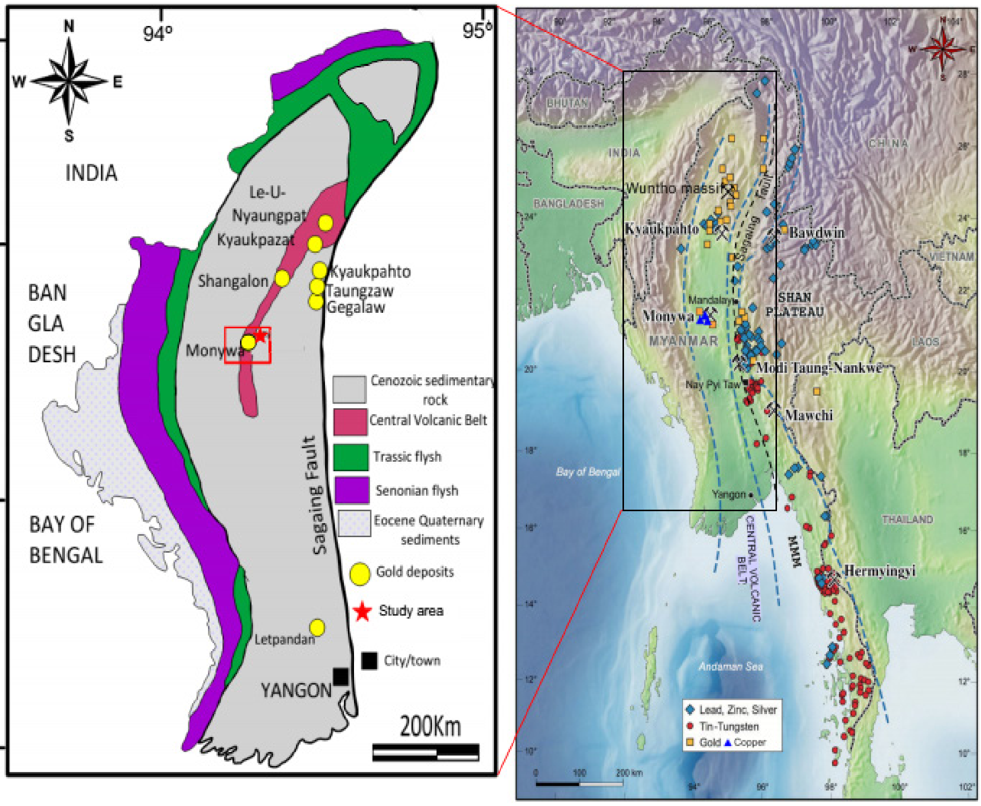

Figure 1. Map showing Central Volcanic Belt (CVB) with major gold deposits of copper-gold and lead-zin, tin-tungsten (right side). Map illustrating the generalized distribution of primary gold deposits from sub-units of CVB (left side) [7,13].

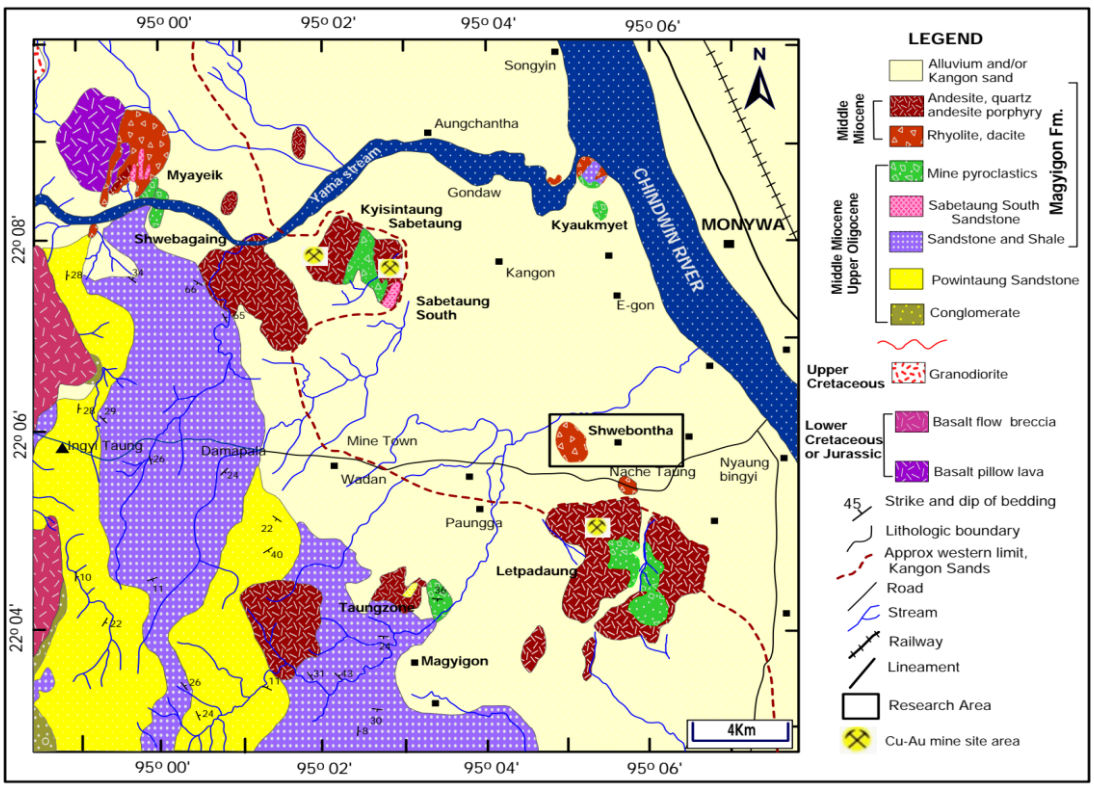

Figure 2. Regional geological map of Monywa copper-gold ore field (Modified after [1]).

3. Local geology

The Shwebontha prospect belongs to the epithermal gold-based metal mineralization [3]. It is located about one-kilometer ENE of the Letpadaung Cu-Au deposit in which active mining (**Figure 2**). The geology of the prospect area (Monywa copper-gold ore field) is described by Oo, T.N., Harijoko. A., Setijadji, L.D, 2021 and Htet, 2008. It is dominated by Upper Oligocene to Middle Miocene stratigraphic unit, named the Magyigon Formation, which consists mainly of rhyolite, hydrothermal breccia, tuff breccia, tuff, tuffaceous sandstone and alluvium deposit (**Figure 3**). In the prospect area, a simplified geological map points out the presence of rhyolite as the major rock unit at the eastern and northern parts of the Shwebontha prospect. Stratigraphically, hydrothermal breccia is the oldest rock unit. Gold-based metal mineralization mainly occurs in the rhyolite belonging to the Central Volcanic Belt in the study area. Mineralization is recognized by gold-bearing silicified massive ore and chalcedonic quartz veins in which sulfides are clustered and disseminated in the rhyolite host rocks. This mineralization vein is intimately associated with a silicic alteration zone characterized by the presence of pyrite, galena, sphalerite, chalcopyrite and gold. Their vein trends generally followed the regional structural trend, which might be related to NE-ENE trending in a direction that is probably considered to be responsible for the formation of epithermal gold-base metal mineralization in the Shwebontha prospect [3].

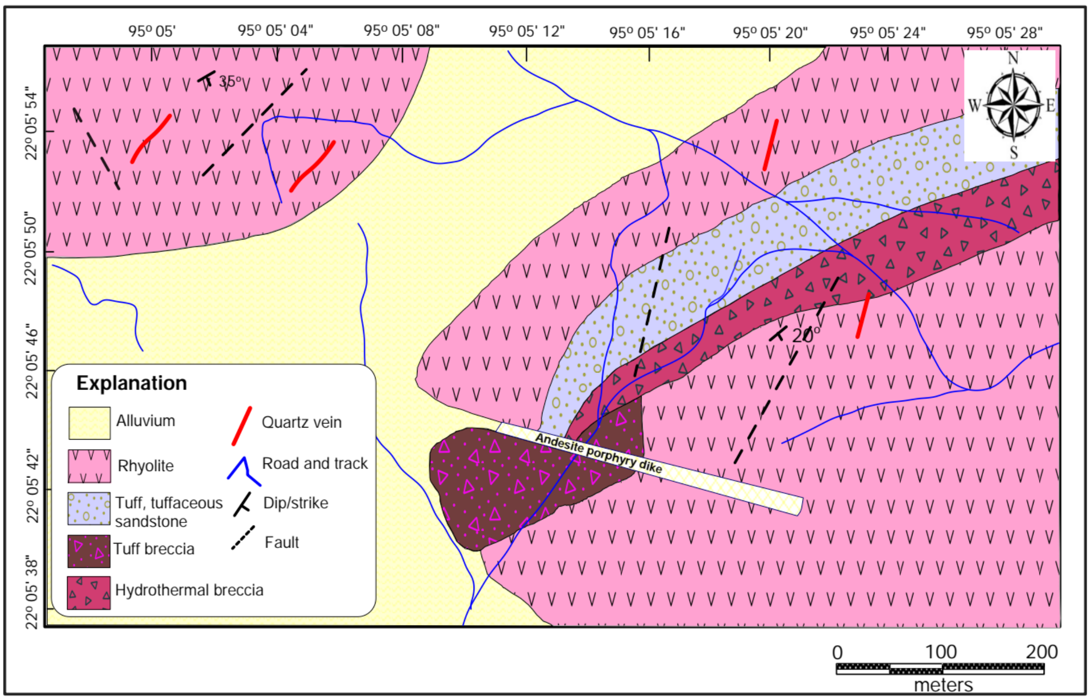

Figure 3. Simplified geological map of the Shwebontha prospect (modified after [4]).

4. Research methods

Methods employed in this study were petrography, X-ray Fluorescence (XRF) and fluid inclusion micro thermometry. A total of twenty-five (25) samples were collected from the surface outcrops in the Shwebontha prospect area, Monywa copper-gold ore field: hydrothermally altered rock (15 samples) and mineralized quartz vein (10 samples). Fifteen samples were prepared for thin sections, doubly-polished thin sections, or polished sections. Thin sections and polished sections were determined petrographically to identify the primary and secondary (alteration) mineral assemblages. A detailed study on ore microscopy of polished thin sections using both transmitted and reflected light was done to observe ore mineral assemblages and textural relationships. Subsequently, a total of 12 representative rock samples were selected for whole-rock geochemistry. The concentrations of major and minor elements of 12 rhyolite rocks were analyzed by X-ray Fluorescence (XRF). On the contrary, five mineralized quartz vein samples were further analyzed by fluid inclusion analysis. The fluid inclusion mico thermometry was performed to obtain information data regarding the temperatures of ore formation and the salinities of mineralizing fluids. Salinities, which are expressed in wt.% NaCl equivalent, were examined from the last ice-melting temperatures using the equation of Bodnar (1993) [14]. All laboratory analyses were undertaken at Kyushu University, Japan.

5. Results and discussion

5.1 Geochemistry of volcanic rock

The volcanic rocks from the Shwebontha prospect mainly constitute rhyolite. The concentration of major (wt%), trace and rare earth elements (ppm) of the rhyolite rocks from the Shwebontha prospect are displayed in (See **Appendix A**). The rhyolite rocks show the SiO_2 contents ranged between (75.1%-79.98%), Al_2O_3 (9.11%-12.75%), FeO*(tot) (0.08%-1.22%), TiO_2 (0.8%-0.10%), MnO (0%-0.1%), MgO (0.44%-0.7%), CaO (0.14%-0.21%), Na_2O (0.50%-0.88%), and K_2O (6.43%-9.73%) (See **Appendix A**). Based on the plotting result in the TAS (Total Alkali versus Silica) diagram of [15] **(Figure 3**) can be confirmed that this unit consists of rhyolite. Volcanic rock compositions were also confirmed by an immobile trace elemental plot (**Figure 4**) by applying Zr/Ti and Nb/Y diagram [16].

Based on the binary plot diagram of SiO_2 versus Na_2O+K_2O [17], volcanic rocks (rhyolites) of the Shwebontha prospect area have displayed the nature of sub-alkaline to alkaline affinity (**Figure 5**). AFM diagram is classified between tholeiitic and calc alkaline differentiation trends in the sub-alkaline magma series. Volcanic rocks (rhyolite) from the Shwebontha prospect are plotted on the AFM diagrams [17]. Triangular AFM plot shows that the rocks are located in the field of the calc-alkaline series (**Figure 5**). The triangular AFM plot shows that the rocks are located in the field of the calc-alkaline series (**Figure 5**). The SiO_2 and some of the major oxide elements cannot be applied because of alteration product in the magmatic evolution processes. For this reason, the incompatible element 'Zr' is used as a replacement for SiO_2. The trace element variation diagram in this study exhibits that Rb, Nb, Ba, Sr and Y versus Zr display positive correlation (**Figure 6**) which are recognized to be mobile with altered volcanic (rhyolite) rock during hydrothermal alteration.

5.2 Hydrothermal Alteration

Mineralization and hydrothermal alteration are observed in the rhyolite host rock unit. Alteration developed around open space mineralized veins at breccia zones. In the research area, three principal kinds of hydrothermal alteration zones have evolved including silicic, argillic and propylitic alteration types. They are examined by optical petrographic observations (**Figure 7**).

Silicification is also a common type of hydrothermal alteration in the Shwebontha propsect, and is closely related to ore mineralization. Silicified rock is characterized by equigranular microcrystalline quartz, hematite and sulfide minerals (**Figure 7**). This alteration is represented by chalcedony, disseminated pyrite with medium to coarse-grained quartz and quartz veinlets in the brecciated sulfide quartz vein and chalcedonic quartz vein (**Figure 7**). And, it also occurs as mineralized veins and is associated with breccias blocks of cement, vein-veinlet and stockwork (up to 2-3 cm width) quartz veins (**Figure 7**). Argillic alteration is characterized by a variable amount of quartz, plagioclase, opaque minerals and clay minerals (sericite, illite, illite/smeciite, and kaolinite). Anhedral to subhedral quartz is found as a phenocryst and fine-grained groundmass (**Figure 7**). Opaque minerals (pyrite) have occurred dissemination (**Figure 7**) which is associated with clay minerals (illite, smectite and quartz). Altered plagioclase was replaced by the yellowish-brown colour of sericite and kaolinite (**Figure 7**). In addition, plagioclase phenocrysts and groundmass were partially replaced by illite, illite/smectite mixed layer mineral, pyrite and quartz minerals. Secondary quartz mainly replaced the groundmass or matrix of the rhyolites (**Figure 7**). According to the microscopic study, the common propylitic alteration minerals are quartz, chlorite, epidote and pyrite (**Figure 7**). The presence of chlorite and epidote can be recorded in the alteration type as propylitic alteration. Altered plagioclase was replaced by quartz, chlorite, epidote, and some clay minerals (**Figure 7**).

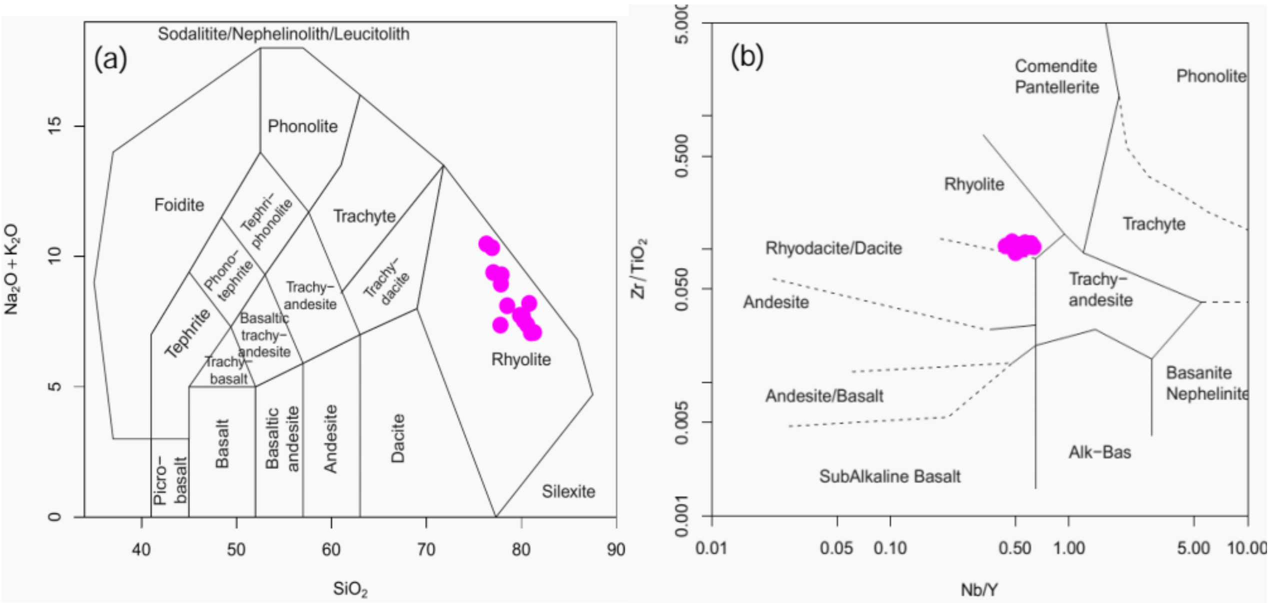

Figure 4. (a) TAS (total alkalis versus silica) classification diagram for volcanic rocks of the Shwebontha prospect [15], (b) Nb/Y vs Zr/TiO_2 plot of volcanic rocks from the Shwebontha prospect [16].

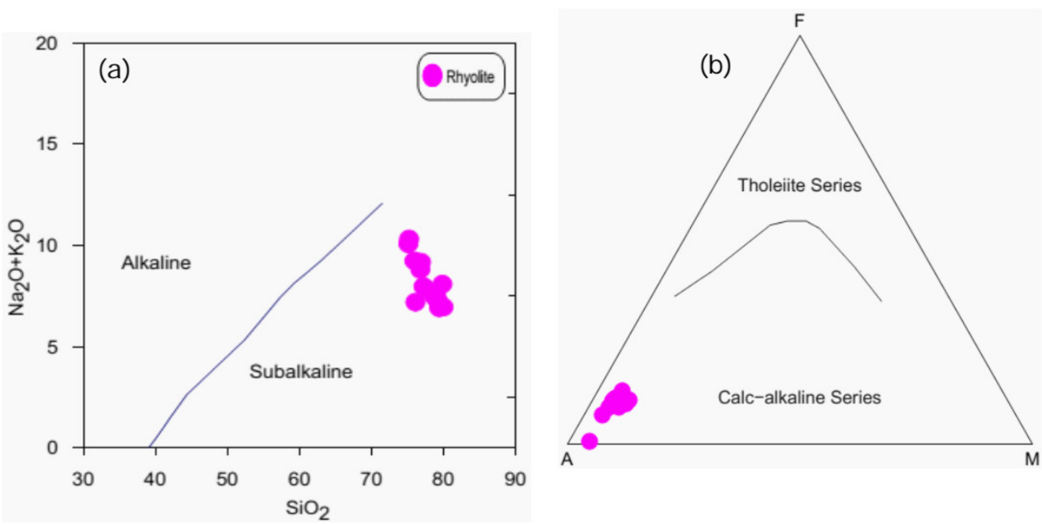

Figure 5. Subalkaline and alkaline classification plot diagram (SiO_2 vs Na_2O+K_2O) [17], AFM classification diagram [17] for volcanic rocks of the Shwebontha prospect.

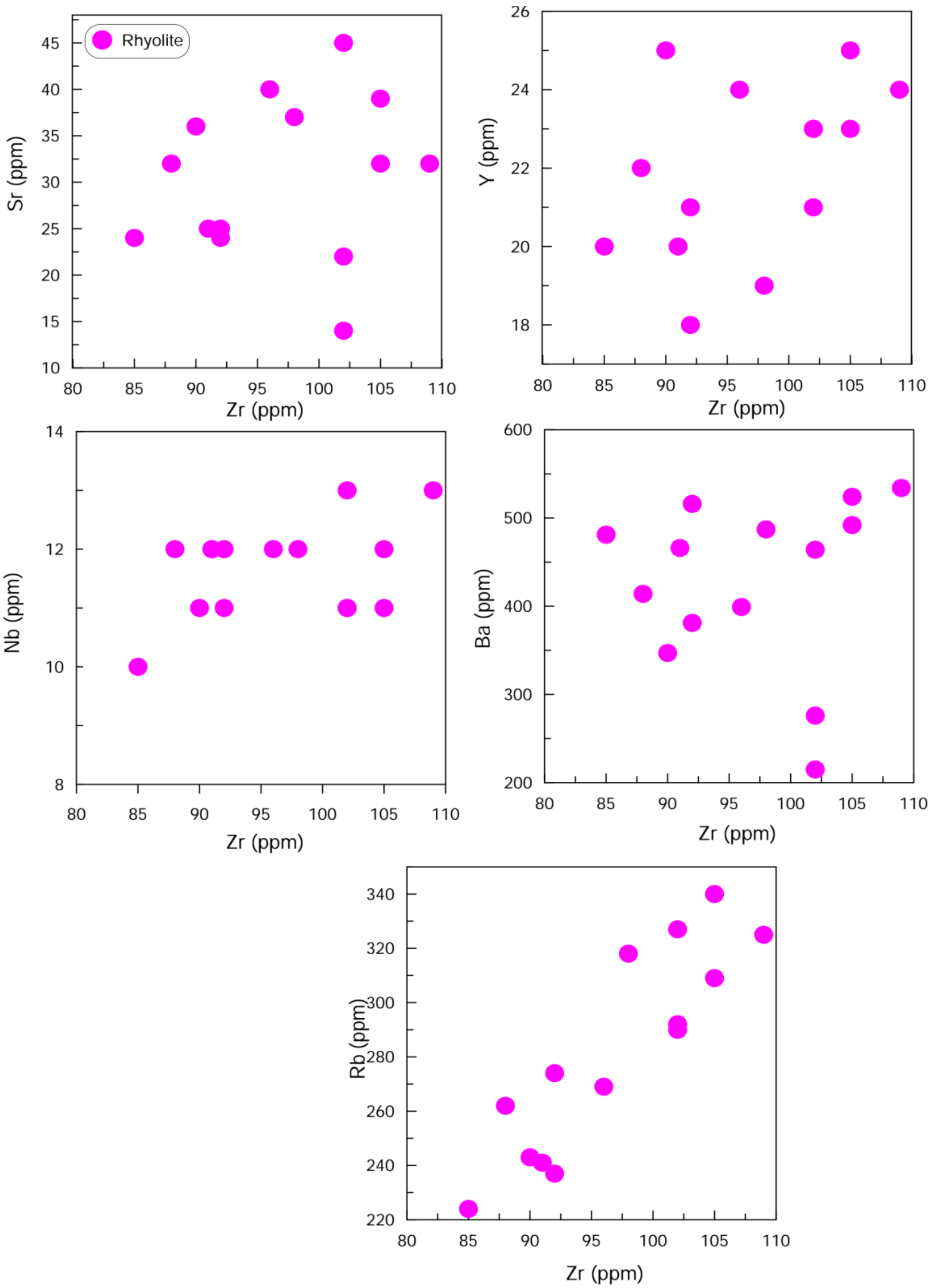

Figure 6. Binary plot diagrams of Rb, Nb, Sr, Ba, Y, and Zr (all in ppm) for rhyolite host rocks at Shwebontha prospect.

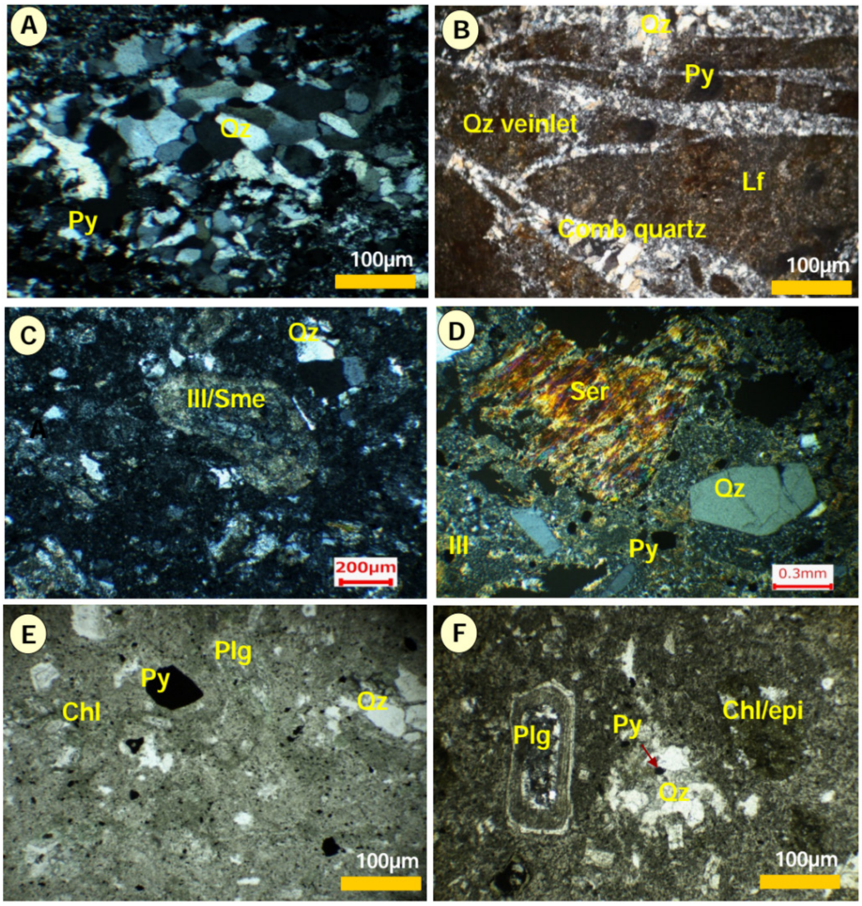

Figure 7. Photomicrographs showing hydrothermal alteration minerals at the Shwebontha prospect. (Qz-quartz, Ill-illite, Sme-smectite, Chl-Chlorite, Epi-Epidote, Py-Pyrite, Plg-Plagioclase, Lf-Lithic fragment).

5.3 Mineralization characteristics

Gold-based metal mineralization is principally hosted by rhyolite rock units in the Shwebontha prospect. Massive orebody of brecciated gold-bearing quartz veins is concentrated on the foremost veins and in zones of argillic altered wall-rocks and oxidized zones (**Figure 8**). The veins belonged to open-space filling and occasionally disseminated nature. Sulfide minerals are also occurred as in the chalcedonic quartz veins alternating with strongly silicified zones cut by cherty or sugary quartz veins in the rhyolite host rock as dissemination (**Figure 8**). Pyrite is the most common sulfide mineral. It observes either as fine-grained disseminations and aggregates in quartz or as infillings in vugs. Primary (hypogene) minerals are pyrite, sphalerite, galena, chalcopyrite, and gold. Secondary (supergene) minerals include covellite whereas gangue minerals are mainly composed of quartz.

Pyrite is distributed and is the most abundant sulfide in the mineralized veins and host rocks. It shows anhedral to euhedral (**Figure 9**), pale yellow to yellowish white. On the other hand, irregular cracks and cataclastic deformation of pyrite are observed in the gangue matrix. Most of the pyrite was replaced by anhedral grains of galena, sphalerite, and chalcopyrite (**Figure 9**). Galena exhibits light grey color and anhedral form. It occurs as a mineral that replaced pyrite (**Figure 9**). Sphalerite is observed as anhedral grain. It is grey and displays internal reflection. Sphalerite appears to have replaced pyrite (**Figure 9**). Gold is significant and occur as native gold or electrum granular grains in euhedral pyrite crystal. It is very fine-grained (1-2 μm), occasionally up to 200 μm. Covellite occurs as a secondary mineral and is generally found as fine-grained disseminated crystals replacing pyrite.

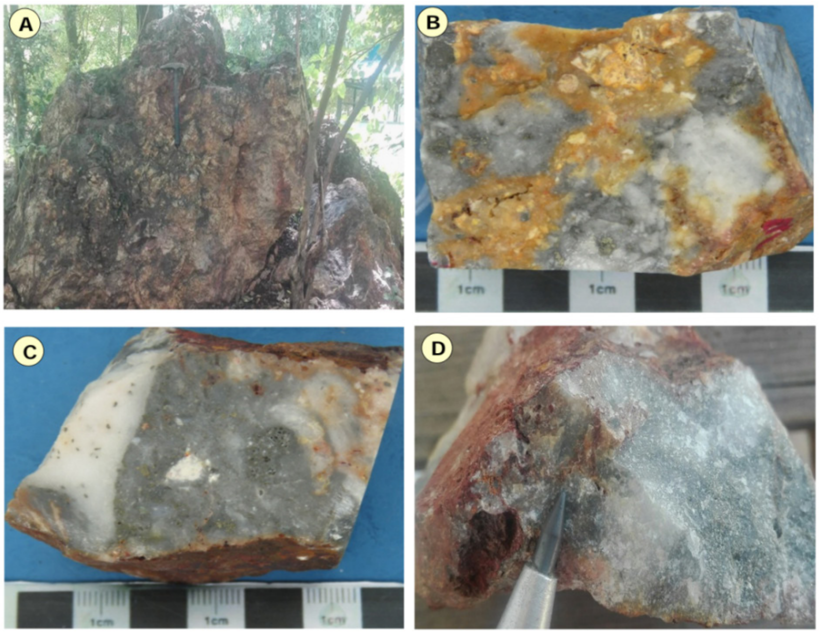

Figure 8. Outcrops and hand specimens showing (a) gold- base metal bearing silicified massive ore, (b,c) gold-bearing brecciated quartz veins and (d) chalcedonic quartz vein in the rhyolite host rock.

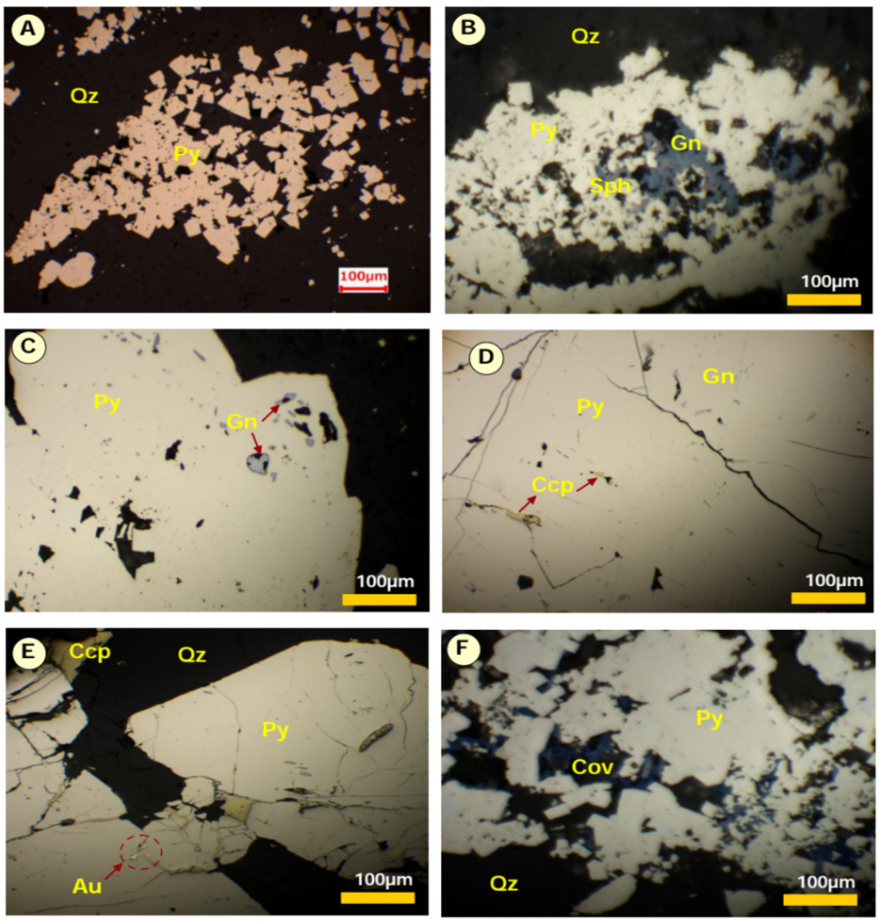

Figure 9. Reflected light photomicrographs of ore mineral assemblages from the Shwebontha prospect. (Py-Pyrite, Gn-Galena, Sph-Sphalerite, Au-Gold, Ccp-Chalcopyrite, Cov-Covellite, Qz-quartz).

5.4 Ore mineralizing fluids

Fluid inclusion micro thermometry was carried out for primary fluid inclusions in quartz from the mineralized quartz veins. The salinity and homogenization temperature resulting from primary fluid inclusions from quartz-hosted inclusions range from 0.35 wt.% to 2.41 wt.% NaCl equivalent and 158 °C to 310 °C respectively (**Figure 10**). The relationship between the salinities and homogenization temperatures of fluid inclusions probably reflects a complex sequence of fluid events, such as isothermal mixing, boiling, simple cooling, mixing of fluids with different homogenization temperatures and salinities and leakage. The data distribution diagram of homogenization temperature and salinity [18] points out that the ore mineralization within the Shwebontha prospect is a result of fluid mixing from various homogenization temperatures and salinities (**Figure 11**). On the other hand, magmatic fluids are thought to be genetically related to fluid salinities of 5-10 wt% NaCl equivalent [19-21]. In comparison, the values of low salinity fluids (less than 3.0 wt% NaCl equivalent) from the Shwebontha prospect suggests that the low salinity fluids of the study area belonged to a dominant origin of meteoric. The salinity from the sample in this study ranges from 0.35-2.41 wt% NaCl equivalent while those of the magmatic fluids range from 5-10 wt% NaCl equivalent. The numbers in magmatic systems are very higher than the results in this study [18]. On the other hand, previous research on fluid inclusions has recognized a close relationship between the salinity and homogenization temperature that is suggestive of the source of the fluid [18,22]. This reveals that the low-salinity ore mineralizing fluids of the Shwebontha prospect were generated by the mixing of a dominant meteoric water phase with small or trace amounts of magmatic fluid. The relationship between salinities and homogenization temperatures of fluid inclusions. The relationship between salinities and homogenization temperature of fluid inclusions is displayed in **Figure 11**.

5.5 Conceptual model of Shwebontha prospect

The conceptual model for the development of the epithermal system in the Shwebontha prospect was based on the emplacement of a reduced, near neutral pH, and dilute fluids formed by the input of magmatic components into deep circulating ground waters level and are typically associated with calc-alkaline to alkaline magmatism, in volcanic arcs low-intermediate and high-sulfidation epithermal system (**Figure 12**). At the initial stage of mineralization, the hydrothermal fluid phase exsolved and concentrated ore-forming metals and volatiles during the ascending, followed by crystallization, and cooling of magma [20]. Along the mineralized ore zones, rising fluids (as a result of pressure release) are heading to a higher elevation where they can be boiling fluid as well as mixing fluid with circulating meteoritic fluids.

In the first stage of epithermal gold mineralization, gold-bearing silicified massive ore as well as chalcedonic quartz vein for the Shwebontha prospect were precipitated at a shallow level by fluid mixing processes of the hydrothermal system. Those mineralized veins are formed by changing fluid conditions where the mixing of fluids is the principal mechanism of the gold and base metals deposition process in this epithermal system. Successive changing of the fluid conditions by fluid mixing resulted in repetitive layers in mineral assemblages such as quartz, carbonate, chalcedony and sulfides. At this phase, gold is precipitated as an electrum. In addition, hydrothermal alteration zones are also occupied as silicification as well as argillic alteration and propylitic alteration zone by interaction with wall rocks and the nature of hydrothermal fluids.

At the second stage of mineralization, as the fluid mixing continued under hydrostatic conditions, the releases of carbon dioxide and hydrogen sulfide gasses increased the pH of the fluid, which could have been derived by the precipitation of gold-bearing silicified massive ore as well as chalcedonic quartz vein for the Shwebontha prospect. In places, gold is deposited as native gold or electrum. This transition is related to a progressive decrease in sulphur fugacity, oxidation state, and acidity [23]. The former represents the high-sulfidation state (e.g., at Letpadaung taung, Kyinsintaung and Sabetaung) and the latter indicates the intermediate to low-sulfidation state of ore-forming fluids (Shwebontha). Here, it does not mean that mineralizations have been generated without having a break; instead, some un-renowned processes can be interrupted the precipitation and ore depositional process. Fluid mixing is believed to be the major cause of gold and base metals deposition in the Shwebontha prospect. Fluid mixing between hot, acidic and saline-bearing ore fluid and cooler meteoric water might be also responsible for gold and base-metals deposition. Based on the geochemical characteristic, ore textures, hydrothermal alteration mineral assemblages and mineralization styles and natures of the hydrothermal fluids, allow interpretation of the low to intermediate sulfidation epithermal system (**Figure 12**).

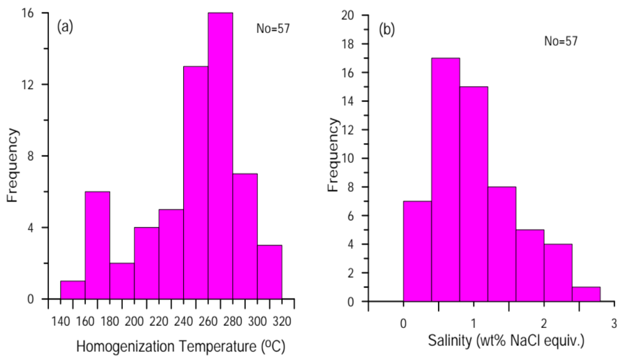

Figure 10. Data distribution of homogenization temperature and salinity histograms of the fluid inclusions from the Shwebontha prospect.

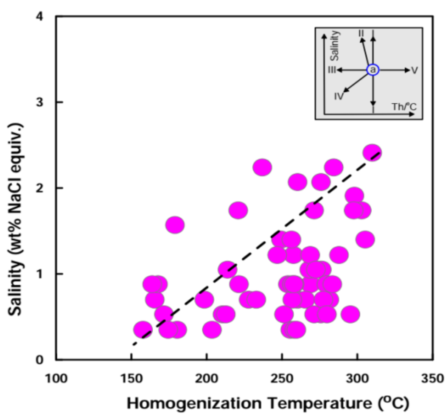

Figure 11. Mixing trend based on homogenization temperatures vs. salinities plot at Shwebontha prospect (modified after [18]). The supplement figure displays salinity and homogenization temperature trends or fluid evolution processes (modified from [22]). (I) isothermal mixing; (II) boiling; (III) simple cooling; (IV) mixing of fluids with different homogenization temperatures and salinities; (V) leakage.

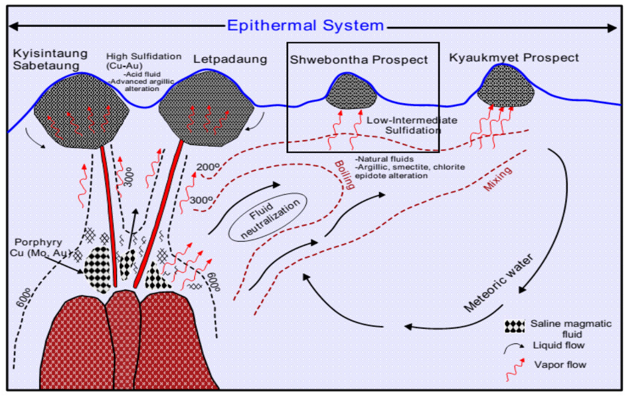

Figure 12. A conceptual model for the development of an epithermal at the Shwebontha prospect area, Monywa copper-gold ore field, central Myanmar (Modified after [4]).

6. Conclusions

The regional tectonic setting of the Shwebontha prospect is characterized by a subduction-related Central Volcanic Belt which plays an important role in the formation of an epithermal system. Alteration/mineralization in the research area is hosted by a sequence of Upper Oligocene to Middle Miocene Magyigon Formation calc-alkaline volcanic rocks (rhyolite). The calc-alkaline host rocks are consistent with magmatic rock associations that are commonly associated with the epithermal deposit. The alteration zones consist of silicic, argillic, and propylitic. The silicic alteration is represented by chalcedony, disseminated pyrite with medium to coarse-grained quartz and quartz veinlets in the brecciated sulfide quartz vein and chalcedonic quartz vein. Argillic alteration is mainly characterized by a variable amount of quartz, plagioclase, opaque minerals and clay minerals (sericite, illite, illite/smectite, and kaolinite. The propylitic is characterized by the selective alteration with dominant mineral assemblages of quartz, chlorite, epidote and pyrite. The mineralization is recognized by gold-bearing silicified massive ore and chalcedonic quartz veins. The principal ore mineral includes pyrite, sphalerite, galena, and gold. In addition, gangue minerals, including quartz, illite, illite/smectite, sericite, chlorite, and epidote have been recorded. The fluid inclusions data and interpretation revealed that mineralization was driven by the mixing of ore mineralizing fluid at an originated temperature of 158-310 °C. The fluid salinity is 0.35-2.41 wt.% NaCl equivalent. Our study suggests that the mineralization style at the Shwebontha prospect is considered to be under an epithermal environment.

Author Contributions

T.N.O and K.Z.O carried out the fieldworks and developed the concepts, designed on this research. T.N.O. collected the data and samples as well as conducted the laboratory analysis and wrote this manuscript with contribution on discussion from K.Z. All authors were contributed in reading, comments and giving the annotations on this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Appendix A. Result of XRF whole rock chemical analyses of volcanic rocks from the Shwebontha prospect.

Sample ID	SR1	SR15	SR14	SR10	SR7	SR20	SR11	SR13	SR5	SR2	SR6	SR17	SR22	R8
Major elements (in wt%)														
SiO_2	76.1	77.1	75.2	79.2	78.9	78.4	79.9	78.9	75.9	76.8	79.8	79.4	75.1	76.8
TiO_2	0.10	0.10	0.10	0.09	0.09	0.10	0.09	0.08	0.09	0.09	0.09	0.08	0.10	0.09
Al_2O_3	12.8	11.3	11.5	10.2	10.4	10.3	9.56	10.0	11.5	10.9	9.11	10.0	11.7	11.08
FeO	0.99	1.12	0.84	0.86	0.80	0.92	0.93	1.22	1.16	0.96	1.07	0.82	0.08	1.19
MnO	0.01	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
MgO	0.54	0.53	0.45	0.55	0.57	0.70	0.67	0.49	0.48	0.46	0.44	0.58	0.47	0.50
CaO	0.14	0.17	0.14	0.17	0.17	0.17	0.16	0.16	0.19	0.21	0.16	0.18	0.14	0.19
Na_2O	0.52	0.56	0.60	0.51	0.52	0.52	0.51	0.64	0.80	0.88	0.62	0.50	0.58	0.77
K_2O	6.69	7.42	9.73	6.75	6.90	7.09	6.46	6.98	8.45	8.30	7.48	6.43	9.51	8.05
P_2O_5	n.d	n.d	n.d	n.d	n.d	0.01	0.01	n.d	0.01	0.01	n.d	n.d	0.01	0.01
H_2O	2.10	1.55	1.27	1.61	1.57	1.62	1.54	1.37	1.31	1.22	1.07	1.88	1.46	1.25
Total	99.9	99.8	99.8	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.85	99.9	99.1	99.9

Appendix A continued

Sample ID	SR1	SR15	SR14	SR10	SR7	SR20	SR11	SR13	SR5	SR2	SR6	SR17	SR22	R8
Trace elements (in ppm)														
V	17	18	14	3	10	14	7	5	13	10	6	0	5	6
Cr	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Co	30	36	42	45	50	27	30	55	50	40	34	36	23	25
Ni	11	13	8	8	8	7	12	9	8	9	13	7	6	11
Cu	2.01	23	31	22	41	24	30	78	49	25	19	31	5	3
Zn	46	50	n.d	26	9	3	n.d	47	18	33	7	12	10	20
Pb	5	9	8	11	22	17	6	n.d	6	23	31	41	23	45
As	13	7	8	6	8	31	43	9	10	12	19	9	7	11
Mo	13	11	11	11	9	11	7	7	10	10	9	8	9	10
Rb	292	290	340	237	241	269	243	274	318	327	262	224	325	309
Sr	14	22	32	24	25	40	36	25	37	45	32	24	32	39
Ba	215	276	524	516	466	399	347	381	487	464	414	481	534	492
Y	21	23	25	21	20	24	25	18	19	23	22	20	24	23
Zr	102	102	105	92	91	96	90	92	98	102	88	85	109	105
Ta	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Nb	11	11	12	12	12	12	11	11	12	13	12	10	13	11