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CHARACTERISTICS AND GENESIS OF LOW SULFIDATION EPITHERMAL GOLD DEPOSIT AT KYAUKMYET PROSPECT, MONYWA MINING AREA, CENTRAL MYANMAR: IMPLICATIONS FOR CONCEPTUAL GENETIC MODEL

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Abstract

The Kyaukmyet prospect is situated in the Monywa mining area, Central Volcanic Belt (CVB), central Myanmar. The main objective of this paper writing is not only to describe the characteristics of low sulfidation epithermal deposit but also to modify the conceptual genetic model of research area. Gold mineralization hosted within rhyolite unit as colloform-crustiform quartz veins associated with gold and base metal (Zn and Pb) sulfide. The primary metallic minerals, in order of abundance, are pyrite, chalcopyrite, galena, sphalerite and gold; gangue minerals are mainly quartz, adularia, calcite, sericite, illite/smectite, and chlorite/epidote. The main types of wall-rock alteration comprise silicic, argillic and propylitic alterations. Microthermometric measurements of primary LV/VL fluid inclusion assemblages in quartz shows that the ore-forming fluids belong to low temperature (160-300°C), low-salinity (0.4–2.1 wt% NaCl equiv.). Estimated trapping hydrostatic pressures are 16 to 24 bars, corresponding to entrapment depths of 170 to 260 m below the paleowater table. The Kyuakmyet prospect is recognized as a low-sulfidation epithermal mineralization derived from a fluid source during a phase change in temperature and pressure interpreted as being related to fluid boiling. According to the characteristics of several varieties including wall rock alteration, ore mineralization and fluid inclusion analysis, our study may reveal to be classified deposit type and implication for conceptual genetic model at Kyaukmyet prospect, Monywa mining area.

Keywords*:* Wall rock alteration, Ore mineralization, Low-sulfidation, Boiling, Genetic model

Introduction

Gold mineralization at Kyaukmyet prospect is located in the western part of Sagaing Fault, Monywa mining area, central Myanmar (Figure 1). This area is northeast 3 km faraway from well-known Monywa mining area (high sulfidation type Cu deposit), central Myanmar. Small scale local gold rush and artisanal working were started since last thirty years ago. This area is also a part of the Central Volcanic Belt (Mitchell et al., 2011, Mitchell et al., 2012, Maung Maung Naing, 2008) which famous for their primary metallic minerals production and distinct geological feature. Generally, The Central Volcanic Belt (CVB) with a NW-SE trend is one of the most important metallogenic belts in Myanmar hosting numerous Cu ± Au±Ag porphyry, skarn deposits (Mitchell et al., 2011, Knight and Khin Zaw, 2015) but locally epithermal gold mineralization (including research area) is also spread along this belt (Figure 1). The geology and characteristics of the Kyaukmyet prospect indicate that it is a volcanic–subvolcanic hydrothermal deposit (Win Min Htet, 2008, Knight and Khin Zaw, 2015).

However, the prospect is still under exploration and lacks quantitative systematic research. The ore forming fluids characteristics and the gold mineralization processes is still

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poorly constrained. Here, we present the first detailed description of gangue and ore mineral assemblages, and outline the alteration and mineralization hosted by the Kyaukmyet prospect.

Combining these data with result of fluid inclusion microthermometric, our study provides insights into the genesis of the Kyaukmyet prospect and may have implication for the regional exploration of gold deposits in the Monywa mining area.

Geological Setting

Myanmar is located in a tectonic setting covering several metallogenic belts, with a high potential for the occurrence of economic tin-tungsten, lead-zinc-silver and gold-copper deposits (Figure 1). In the recent past in Myanmar, there were only small artisanal mines exploiting near surface oxidized zones for gold and copper. No systematic exploration for gold and copper had been carried out using modern exploration techniques; several gold and copper deposits cropping out remained unexplored. Myanmar has an enormous endowment of mineral deposits including resources of antimony, lead, zinc, copper, gold, tin, tungsten, chromium, nickel and precious jade, rubies, sapphires and diamonds. These mineral deposits are found within specific belts or provinces, and were formed during specific metallogenic epochs during the Phanerozoic (Gardiner et al., 2015). Copper and gold belts occupy the central portion of Myanmar, in the Central Volcanic Belt and west of the Sagaing Fault (Figure 1).

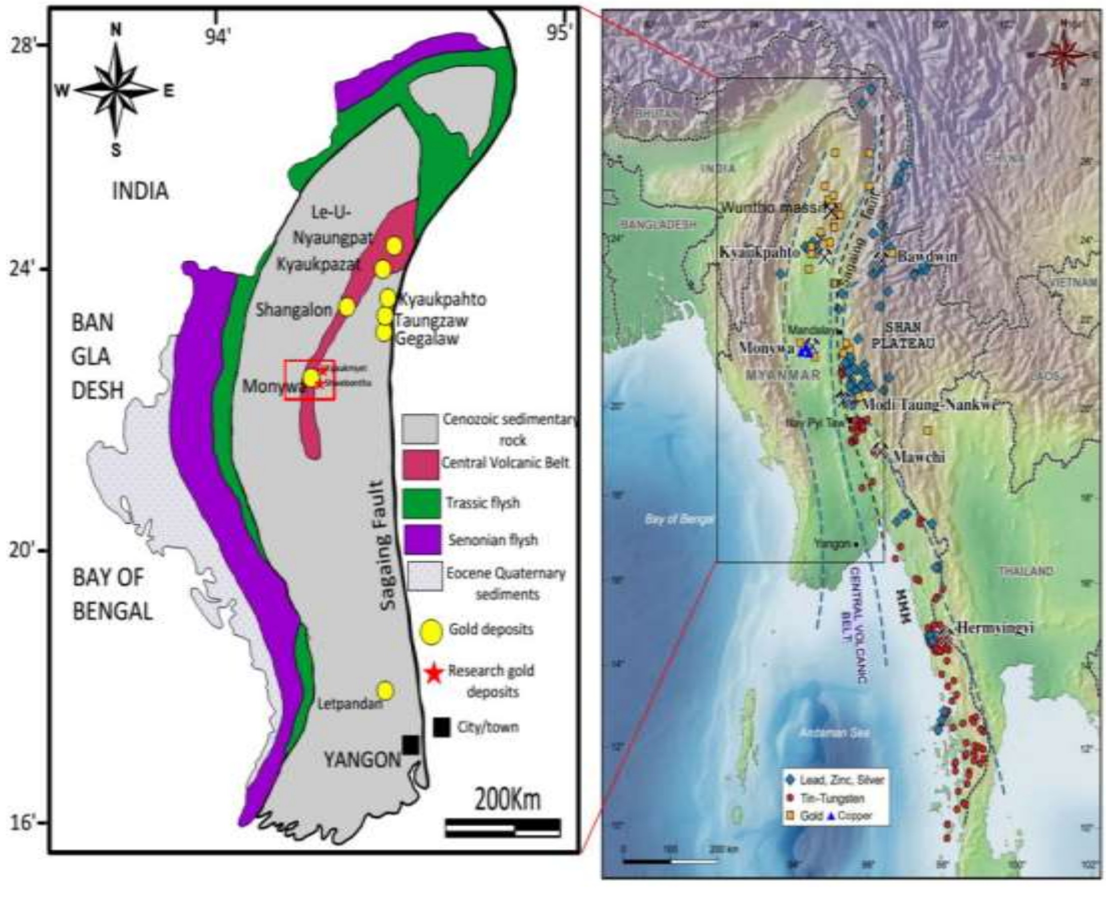

Figure 1. Map illustrating the location of N-S trending Central Volcanic Belt with some primary gold deposits (Modify after Gardiner et al., 2015).

Central Volcanic Belt is generally represented by a discontinuous belt of both plutonic and volcanic rocks. The Central Belt of the region is endowed with abundant precious and base metal resources and has been a source of gold and copper. Porphyry style Cu-Au and its related epithermal Au deposits (e.g Shangalon, Le-U-Banmauk, Kyaukpazat, and Monywa mining area) are found along the Central Volcanic Belt. The Monywa mining area is located in the Central Volcanic Belt, within the central part of Myanmar (Figure 1). In the Monywa mining area, volcanic rocks are mainly intruded by the Upper Cretaceous age of granodiorites (Mitchell et al., 2011). In general, the basement rocks are mostly distributed by volcanic rocks including andesite, quartz andesite porphyry, dacite, and rhyolite in the Magyigon Formation (Figure 2). Most copper-gold (high-sulfidation Cu type) and gold-silver (low-sulfidation type) and base metal deposits between the Chindwin River and Powintaung sandstone are mainly generated by the Oligocene-Miocene Magyigon Formation (Figure 2).

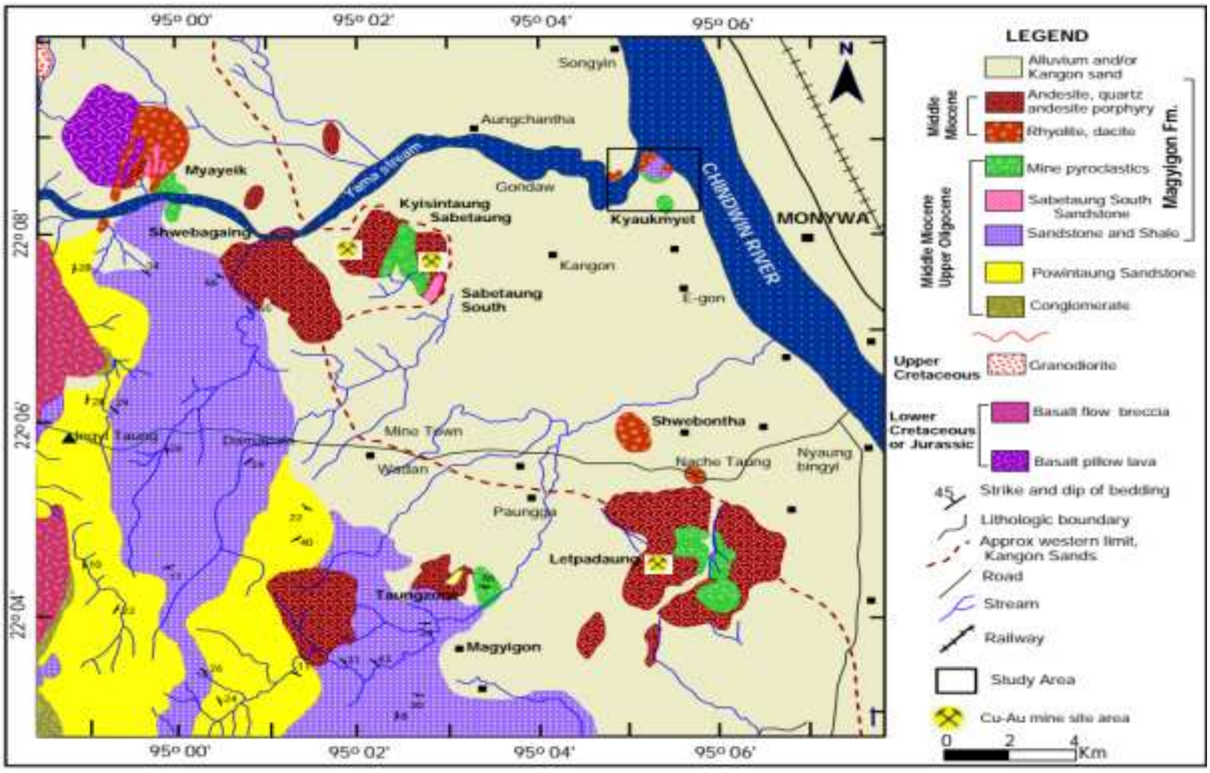

Figure 2. Simplified regional geological map of Monywa mining area and the black rectangle is the Kyaukmyet prospect (Modified after Mitchell et al., 2011).

Research Methods

Methods conducted in this research comprised of petrography, SEM-EDX and fluid inclusion method. A total of fifteen (15) samples were taken from the surface outcrops in the Kyaukmyet prospect, Monywa mining area: hydrothermally altered rock (7 samples) and mineralized quartz vein (8 samples). Ten samples were prepared for thin sections, doubly-polished thin sections, or polished sections. Thin sections and polished sections were determined petrographically to examine the primary and secondary (alteration) mineral assemblages. A detailed study on ore microscopy of polished thin sections using both transmitted and reflected light were performed to observe ore mineral assemblages and textural relationships. Some of the ore minerals were confirmed again by scanning electron microscopy with energy dispersive X-ray (SEM-EDX). Subsequently, a total of 5 representative ore samples were selected for fluid inclusion analysis in order to determine ore formation temperature and salinity. All laboratory analyses were done at the Department of Earth Resources Engineering, Kyushu University, Fukuoka, Japan.

Results and Discussion

Wall Rock Alteration

The hydrothermal mineralogy and spatial association of different alteration assemblages in the Kyuakmyet prospect was studied by detailed petrographic examination. Three main hydrothermal alteration types are distinguished in the Kyuakmyet: silicic, argillic and propylitic alterations (Figure 3). Silicic alteration is covered with mineralization vein but the groundmass is strongly silicified. There is a texture of bladed quartz, carbonate±adularia vein (Figure 3a,b). They are commonly exhibited lattice bladed calcite replaced by quartz, adularia and pyrite. Argillic alteration mostly occurs in rhyolite rock (Figure 3c). Argillic alteration is pervasive and altered-outcrops are generally ash white colour on the weather surface and soft (Figure 3c). Argillic alteration is characterized by the replacement of plagioclase by illite/smectite, quartz and minor amount of pyrite (Figure 3d). At locations that relatively distance to the mineralization, outcrops of propylitic alteration were found in the study area. As can be seen in Figure 3e, an indication of the propylitic alteration occurred in altered rhyolite which is shown by the greenish color of the outcrop. The greenish colour represents chlorite and epidote, the key minerals of propylitic alteration (Corbett and Leach, 1998). Under the microscope, the presence of chlorite, epidote, and sericite that selectively altered or replaced the groundmass plagioclase was observed in thin section (Figure 3f).

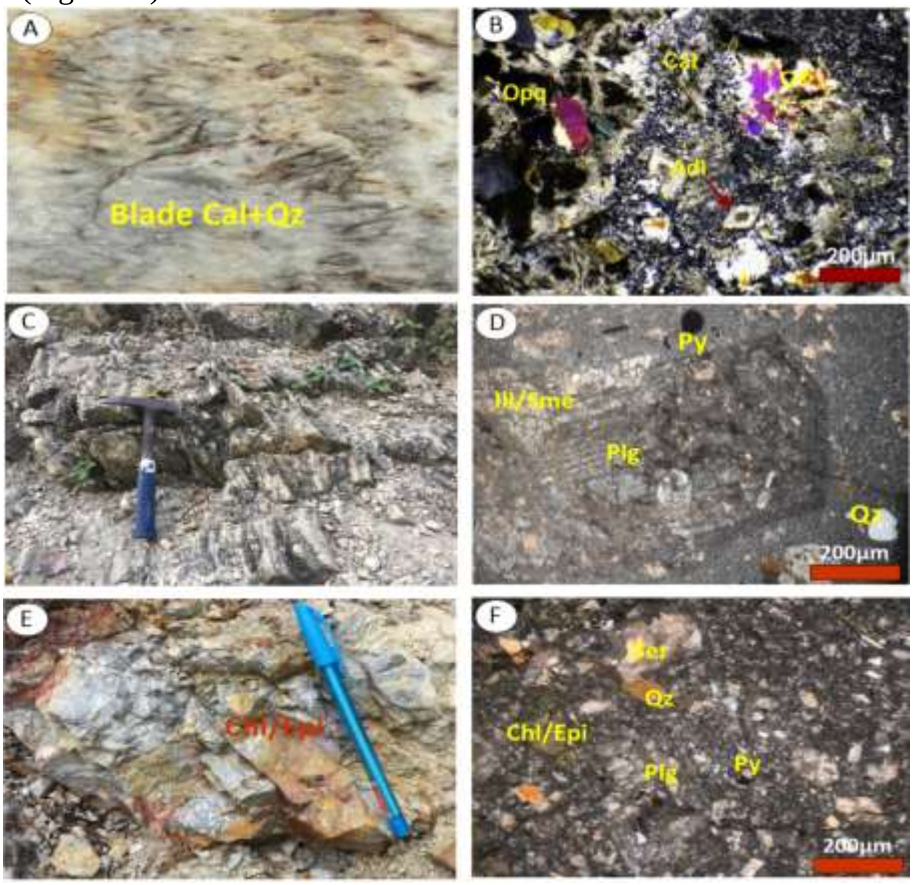

Figure 3. Outcrops of (a) the silicic alteration, (c) argillic-altered rhyolite rock and (e) propylitic altered rhyolite rock, (b,d,f) The results of petrographic examination of alteration mineral assemblages. Abbreviations: Py-pyrite, Adl-adularia, Chl-chlorite, Epi-epidote, Ser-sericite, Ill-illite, Sme-smectite, Qz-quartz, Cal-calcite, Plg-plagioclase, Opq-opaque

Mineralization Characteristics

The mineralization within the Kyuakmyet prospect is hosted by massive altered rock and gold-base metal-bearing colloform-crustiform quartz–sulfide veins, both of which are hosted by rhyolite rock of the Magyigon Formation. Based on megascopic and microscopic observations, the veins are made up of silica minerals particularly quartz and sulfide minerals (pyrite, chalcopyrite, galena, sphalerite and electrum/gold). The texture of the veins based on megascopic observations consist of colloform-crustiform texture of gold-base metal bearing quartz veins (Figure 4). Mineralization veins mostly occur as replacement and fracture filling types in rhyolite rock unit.

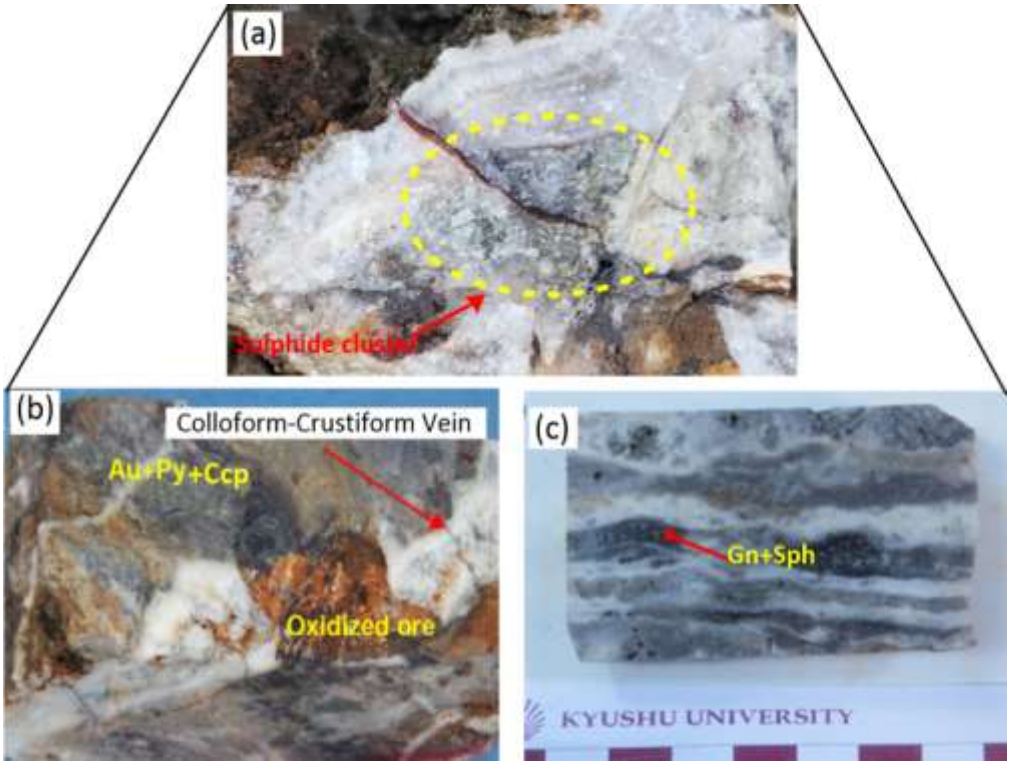

Figure 4. (a) Outcrop nature of symmetrical concentric banding of colloform-crustiform quartz vein texture (b,c) Hand specimens showing colloform-crustiform textures of gold-base metal bearing quartz veins in rhyolite host rock at Kyaukmyet prospect.

Megascopic observations and ore microscopic observations show that the principal ore minerals present in the study area include: pyrite (FeS_2), galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$) and gold (Au). Among them, pyrite is the most dominant sulfides in the mineralized veins and host rocks. It displays euhedral (cubic form) (Figure 5a,c), pale yellow to yellowish white. Chalcopyrite occurs as anhedral and irregular grain as well as enclosed in euhedral pyrite crystal (Figure 5). Sphalerite is observed as anhedral grains. It is grey and shows internal reflection. Sphalerite appears to have replaced (Figure 5b). Galena exhibits light grey color and anhedral form. It occurs as a mineral that replaced pyrite (Figure 5b). Electrum observes as free grains or locked in the euhedral pyrite crystal (Figure 5c). Generally, electrum grain is less than 80% Au with larger size between 100-200 µm (Figure 5d).

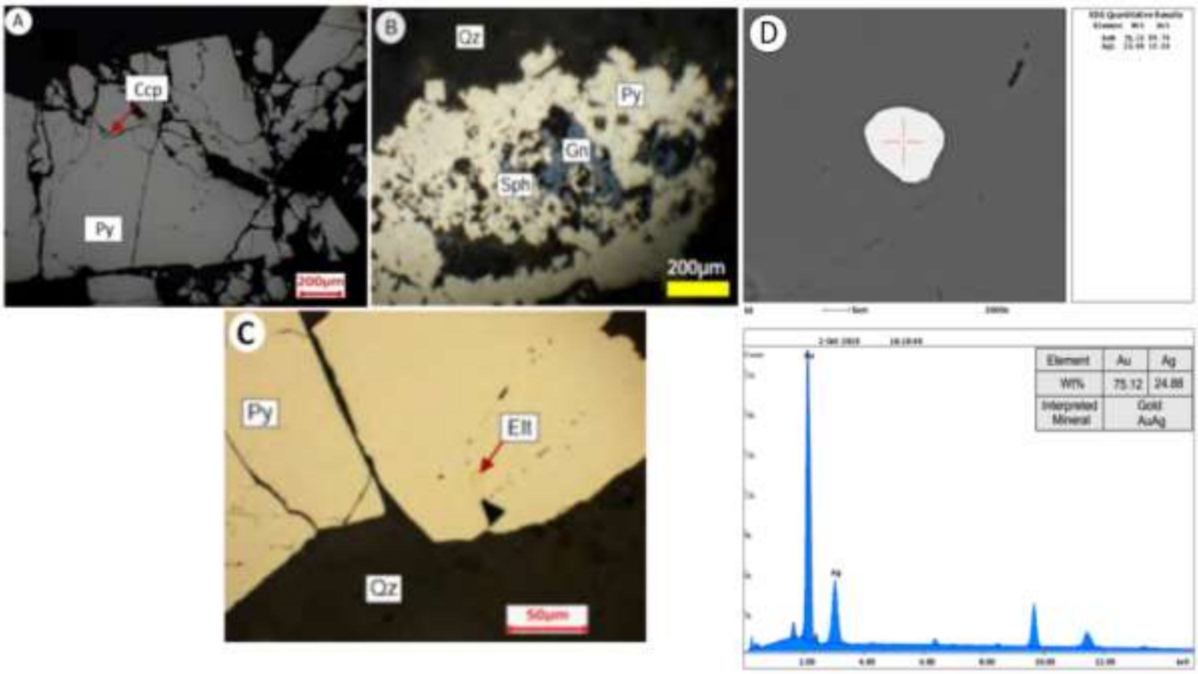

Figure 5. (a-c) Common primary metallic mineral assemblages, (d) Back scattered image of electrum grain with elemental compositions at Kyaukmyet prospect. Abbreviation; Py-pyrite, Ccp-chalcopyrite, Sph-sphalerite, Gn-galena, Elt-electrum, Qz-quartz.

Fluid Inclusion Microthermometry

Microthermometric measurements were carried out for fluid inclusions in quartz veins from the Kyaukmyet prospect. Two types of fluid inclusions were classified in quartz in the gold-base metal bearing colloform-crustiform veins. They are liquid-rich inclusions with consistent liquid-to-vapor ratio and coexisting liquid-rich and vapor-rich fluid inclusions (Figure 6).

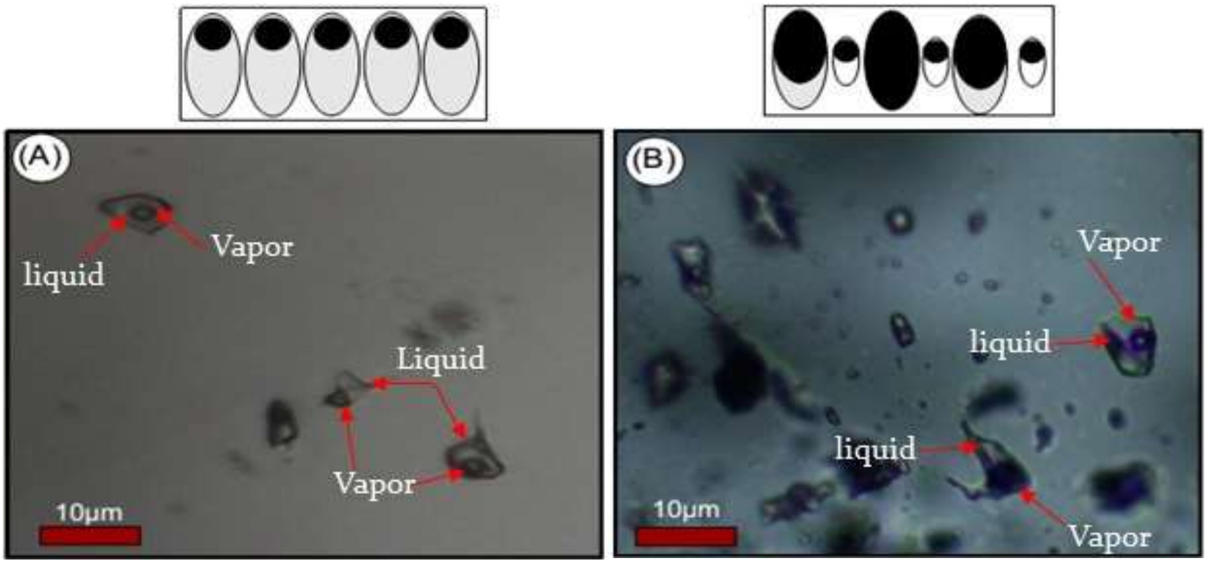

Figure 6. Fluid inclusion types observed in quartz at Kyaukmyet prospect (a) containing liquid-rich inclusions with consistent liquid-to-vapor ratio, indicative of non-boiling, (b) coexisting liquid-rich and vapor-rich fluid inclusions, indicative of boiling condition.

Characteristics of the ore-forming fluids in quartz

The fluid inclusion data are shown in Figure 7. The homogenization temperature of fluid inclusions in quartz have between 160 and 300 °C, with an average temperature of 230 °C. The salinities of fluid inclusions in quartz ranged from 0.4 to 2.1 wt% NaCl equivalent.

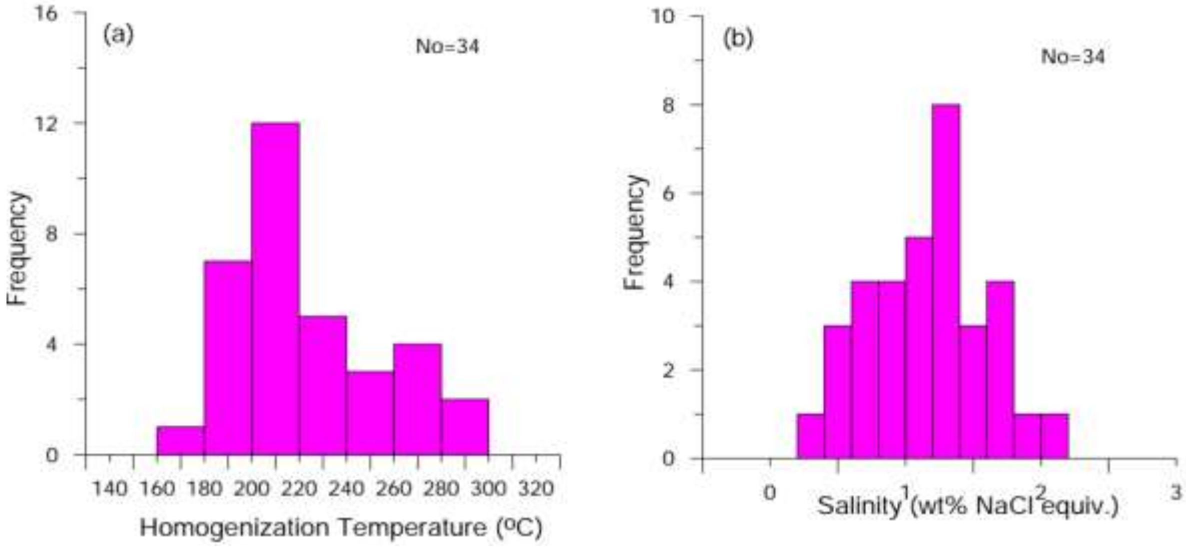

Figure 7. Histograms of homogenization temperatures and salinities for fluid inclusions in colloform-crustiform texture of gold-base metal bearing quartz veins at Kyaukmyet prospect.

Plotting these fluid inclusions data on a bivariate diagram of salinities (wt% NaCl equivalent) versus homogenization temperature (Wilkinson, 2001) indicates that the mineralization within the Kyaukmyet low-sulfidation epithermal gold deposit makes a recording the fluid boiling indicators (Figure 8a).

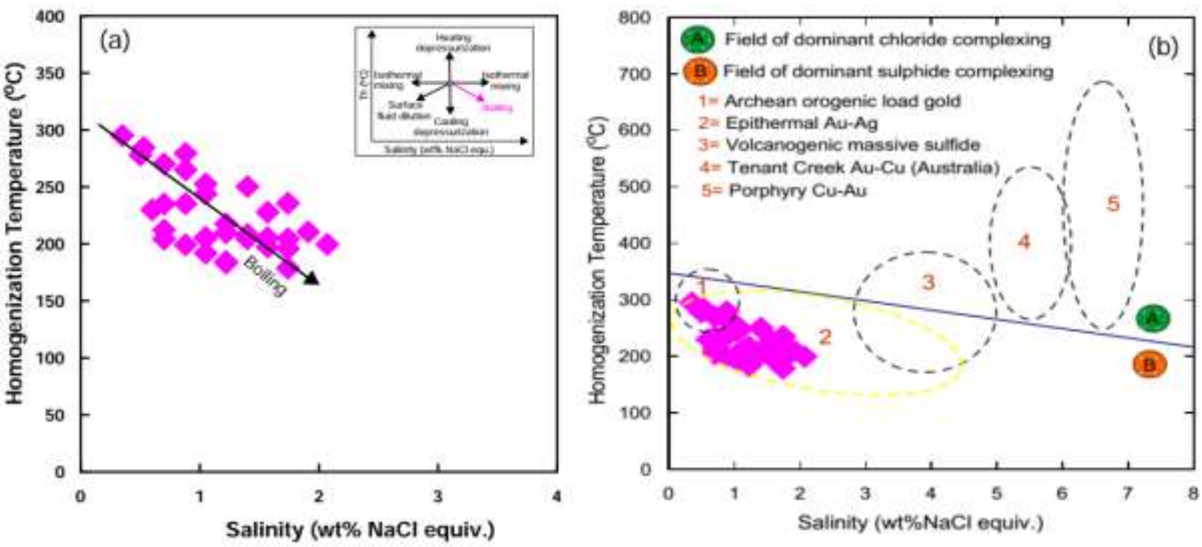

Figure 8. (a) Correlation of homogenization temperature versus salinity (wt% NaCl equiv.) for fluid inclusion assemblages **(**Wilkinson, 2001), (b) Homogenization temperature versus salinity diagram of the Kyaukmyet prospect for comparison stabilities of chloride and sulfide complexes with respect to temperature (Pirajno, 2009).

In a subsequent study**,** the results obtained from fluid inclusion salinity and homogenization temperature studies were plotted on homogenization temperature versus salinity diagram of hydrothermal mineralization systems (Large et al. 1988) in Figure 8b. The diagram had five distinct areas which were 1 -Archaen orogenic gold 2-epithermal gold-silver 3-volcanogenic massive sulfide 4-Australian Tenant creek Cu-Au deposits and 5-porphyry Cu-Au deposits respectively. As it was illustrated in the diagram, all fluid inclusion analysis data are located within the second field which represents epithermal Au-Ag deposit where the dominant transport for metal was as sulfide complexation. It is further indicated that the causes of deposition from sulfide complexes are: 1) pressure release and boiling; 2) oxidation, which decreases the sulfide contents and the pH (Pirajno, 2009) (Figure 8b).

Moreover, the first peak salinity ranges are also not different (0.4 to 2.1 wt% NaCl equiv.) and it assumes a mean salinity 1.25 wt.% NaCl equiv. of salinity on the curve. The formation temperature estimated from the *Th* data can be used to determine the formation depth of the veins. Boiling point curve of (Hass, 1971) was applied (Figure 9) and the minimum formation depth is estimated at 170-260 m for the Kyaukmyet prospect below the paleowater. This depth is equivalent to hydrostatic pressure around 16 to 24 bars for the Kyaukmyet prospect (Figure 9). The resulted paleodepths and pressures estimation at Kyaukmyet prospect reveal that it formed within low sulfidation epithermal system of Sillitoe and Hendenquist (2003) that generated at depths in 100-1000m and pressure less than 10 MPa (100 bars).

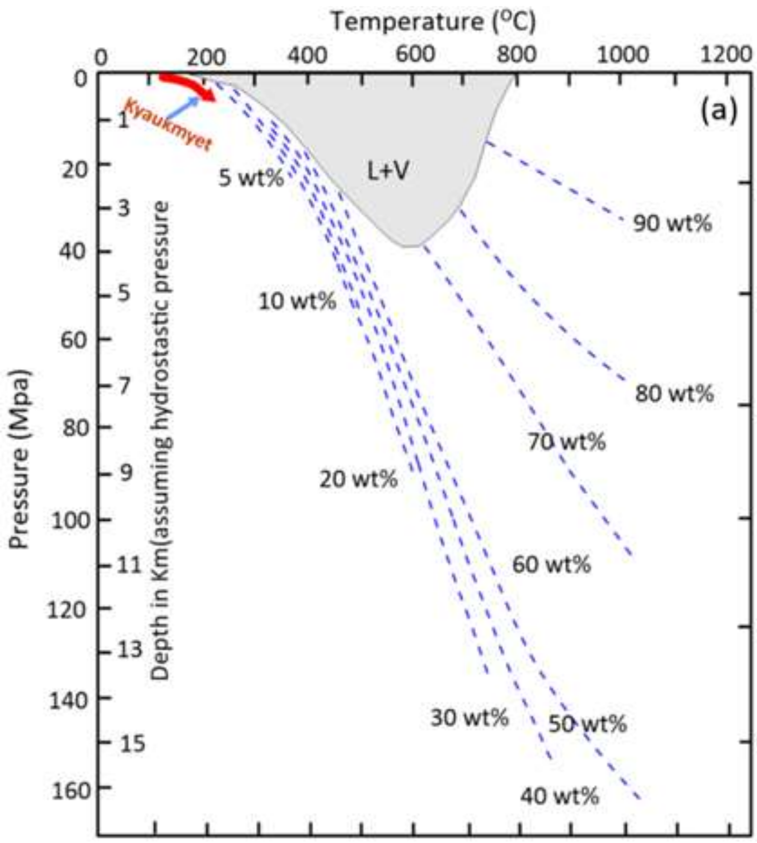

Figure 9. Estimation of paleodepth and pressure for fluid based on (Hass, 1971).

Conceptual Genetic Model

One of the main objectives of this research is to develop a genetic model of epithermal gold mineralization system at the Kyaukmyet prospect, Monywa mining area. Based on the nature and characteristics of hydrothermal alteration, ore and gangue minerals assemblage, quartz vein textures, fluid inclusions petrography and microthermometric data including formation temperature, pressure, salinity, estimate formation of paleo-depth as well as other relevant geological setting, the genetic model for the formation of epithermal gold mineralization system in the Kyaukmyet prospect was established (Figure 10).

At the stage of ore mineralization, hydrothermal fluid phase exsolved and concentrated ore-forming metals and volatiles during the ascent, followed by crystallization, and cooling of magma (Hedenquist and Lowensten, 1994). Along the mineralized ore zones of rising fluids (as a result of pressure release), the fluids are heading to higher elevation where it can be boiling as well as mixing with circulating meteoritic fluids. In the stage of mineralization, gold-base metal bearing colloform-crustiform quartz veins of the Kyaukmyet prospect was precipitated in shallow level by both of fluid boiling and fluid mixing processes. In fact, those mineralized veins formed by changing of fluid conditions where mixing of two fluids and boiling are the principal mechanism of gold and base metals deposition process in this low-sulfidation epithermal deposit. Successive changing of the fluid conditions by fluid boiling and fluid mixing resulted in repetitive layers in mineral assemblages such as quartz, carbonate, adularia and sulfides. At this phase, gold is precipitated as electrum. In addition, hydrothermal alteration zones are also occupied as silicification as well as argillic alteration zone by interaction with wall rocks and nature of hydrothermal fluids. Genetic model for the development of the epithermal gold mineralization system in the Kyaukmyet prospect was based on the emplacement of an reduced, near neutral pH, and dilute fluids formed by the input of magmatic components into deep circulating groundwaters level and are typically associated with calc-alkaline to alkaline magmatism, in volcanic arcs low sulfidation epithermal system (Figure 10), which is similar to the developments of low sulfidation epithermal system proposed by Hedenquist et al., 2000.

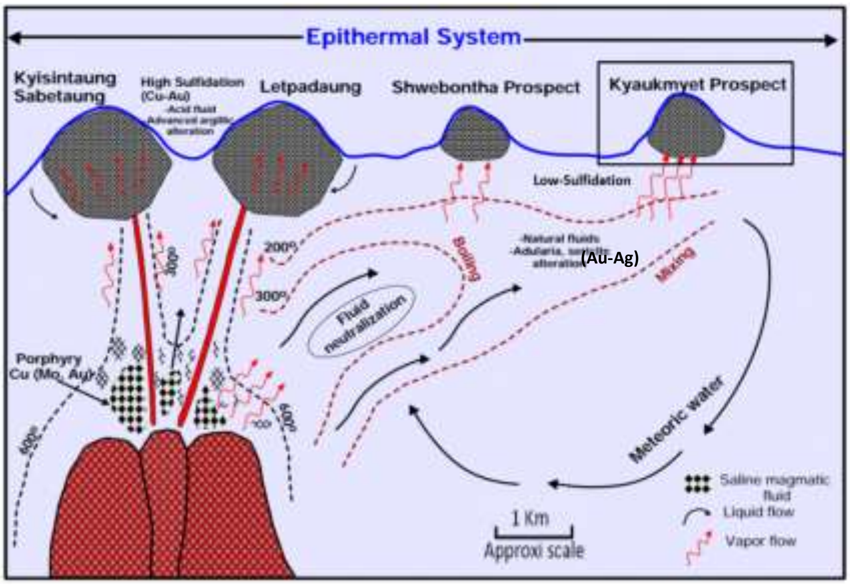

Figure 10. Conceptual genetic model for the formation of epithermal gold mineralization system at Kyaukmyet prospect, Monywa mining area, central Myanmar (Modified after Win Min Htet, 2008).

Concluding Remarks

Detailed field observations and previous exploration results show that ore mineralization found as gold-base metal bearing colloform-crustiform quartz veins texture which are mainly hosted in rhyolite rock unit. The alteration mineral assemblages of the Kyuakmyet prospect comprise quartz, adularia, sericite, illite, smectite, chlorite, epidote and calcite, and the primary sulfide minerals are pyrite, chalcopyrite, sphalerite, galena and gold. Those quartz vein textures and mineralogy in this research belong to typical characters of a low-sulfidation epithermal system. Based on the fluid inclusion petrography, the coexisting liquid-rich and vapor-rich fluid inclusions are observed as boiling indicator. The boiling of hydrothermal fluid is believed as a cause of primary metallic minerals deposition. Microthermometric fluid inclusion analysis portrays that ore mineralization occurred at the temperature of 160-300^{o} C, the low salinity of 0.4-2.1 wt.% NaCl equiv., the minimum hydrostatic pressure of about 16-24 bars, which is equivalent with 170-260 m below paleodepth. Therefore, according to the characteristics of wall rock alteration, vein textures and ore mineralization as well as paleodepth in the Kyuakmyet prospect is classified as a low sulfidation epithermal system as well as useful concept for exploration targeting of ore mineralization at Kyaukmyet prospect, Monywa mining area.

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