# Evaluating the Geochemical Characteristics, Fluid Evolution and Ore Genesis of Gold and Associated Mineralization at Legyin Gold Deposit, Southern Bamauk, Sagaing Region, Myanmar

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## Abstract

Several primary gold deposits are found in Sagaing Region, northern Myanmar. Legyin gold deposit is located in Kawlin-Wuntho Block of the Central Magmatic Volcanic Belt (CMVB). The exposed rock units are andesite (Mawgyi Andesite) of Cretaceous age, mudstone and phyllite (Shwedaung Formation, Upper Triassic), sandstone (Wabochaung Formation) of Miocene age and granodiorite of Mesozoic and Paleogene age. The gold mineralization is mainly hosted by Mawgyi andesite. The aim of this study is to evaluate the geochemical characterisitcs, fluid evolution, ore genesis of gold and associated mineralization at Legyin gold deposit. Based on the mineral assemblages and cross-cutting relationship, two types of veins are recognized. Sericite, epidote, calcite and chlorite are the main alteration minerals. Atomic Absorption Spectrum (AAS) results show the potential of gold range from 0.1 to 2.6ppm. Three types of fluids inclusions were identified. The measured fluid inclusions are 185°C and 28 bars, 170 °C and 26 bars, and 150 °C and 20 bars with correspondence to the depth of 300 m, 280 m, and 210 m, respectively. Based on the geological investigation, ore mineralogy, the alteration mineral assemblages, the nature of mineralization and the ore forming fluids, the gold and associated mineralization from the Legyin gold deposit can be recommended as epithermal type deposit.

**Keywords:** Epithermal deposit, Mawgyi andesite, fluid inclusion, Legyin prospect, Sagaing Region

## 1. Introduction

Myanmar is well known for the ore deposits such as tin, tungsten, gold, copper, lead, zinc and antimony. Among them, Both primary and placer gold deposits are also high potential mineral resources in Myanmar (Figure 1). The most common types of gold deposits in Myanmar can be classified as mesothermal deposits, epithermal deposits, slate-belt deposits, porphyry-related gold deposits, granite related gold deposits, ophiolite-related deposits, placer types and some unclassified deposit types.

Gold mineralization in Myanmar can be grouped under three major provinces; (1) Wuntho massif; epithermal gold-quartz veins occur in the volcanics and sediments of late Tertiary age, which is made up by gold occurrences of Bamauk, Pinlebu, Wuntho, Kawlin and Kanbalu; (2) the western and northern margins of tthe Shan-Tanintharyi Belt; where the gold mineralization is hosted by the epimetasediments of the Chaung Magyi Series of Precambrian age, and the metamorphic rocks of the Mogok Series; and (3) the gold mineralization is associated with the volcanics of the ophiolite sequence. Quartz veins with gold mineralization are very widespread in the Wuntho volcanic-plutonic region and on the western margins of the Shan Plateau in the Slate Belt and the Mogok Metamorphic Belt (MMB).

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In Northern Myanmar, several auriferous quartz veins occur in Banmauk-Wuntho district: the Naung-Pat, Le-Oo, He-Chein, Thone Myae Song, Legyin, Nanaw, Nankhin and Kyaukpazat, Shangalon, Monywa–Salingyi and the Myesaytaung (Lepandan) (Figure 1, Right). Among them, the Legyin gold prospect is one of the high potential gold occurrences. The main purpose of this paper reveal the ore genesis and fluid evolution of the gold mineralization in Legyin area.

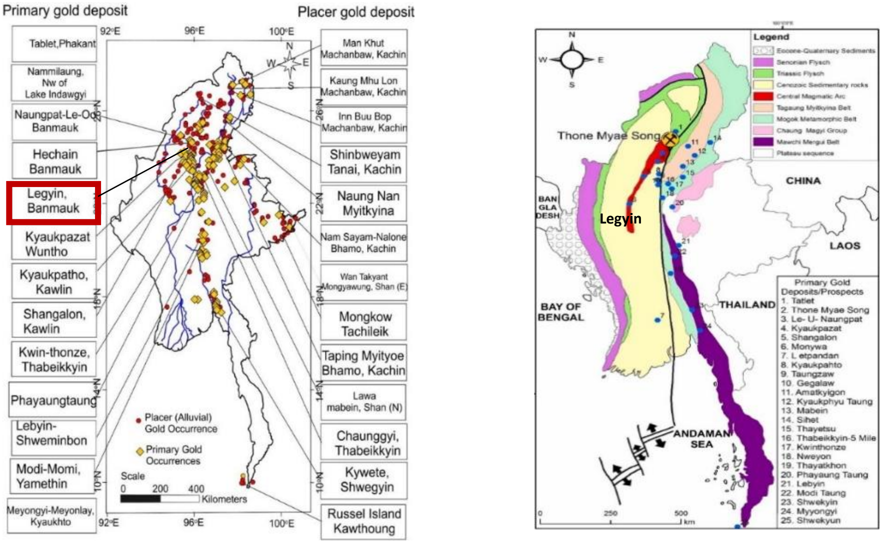



Figure 1. Primary and placer gold occurrences in Myanmar (Left) and The major tectonic belts and location of famous gold deposits in Myanmar including the Legyin gold deposit (Right) (Mitchell et al., 1999; Khin Zaw et al., 2014; Ye Myint Swe et al., 2017)

## 2. Samples and Methods

During the field investigations, total 200 samples of host rocks, altered rocks, and ores were collected from the mine site and around at the Legyin gold deposit. Thin sections and polished sections were made to identify the minerals and their textural characteristics, alteration minerals and ore minerals were observed by polarizing and ore microscope. X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) were conducted for the determination of chemical composition and ore minerals. About 100 fluid inclusions in five vein quartz samples were measured.

## 3. Background Geology

The principle stratigraphy is composed of Mawgyi Andesite of Cretaceous age, phyllite and mudstone of the Shwedaung Formation in the age of Upper Triassic, sandstone of the Wabochaung Formation in the age of Miocene and granodiorite in the age of Mesozoic and Paleogene. The Mawgyi Andesite is widely distributed in the study area. It overlies the tuffaceous sedimentary rocks of the Shwedaung Formation and schists: a succession up to 2,000 m thick of volcanic and volcanoclastic rocks with minor sedimentary units by United Nations (1978). The mineralized quartz veins are mainly hosted by andesite and basaltic andesite. Granodiorite is mainly found in the western part of the study area which has been intensely weathered in some localities.

The diorite, quartz diorite, granodiorite, and adamellite with lesser amounts of micro-leucogranite, dolarite and gabbro are well distributed (Figure 3). The regional geological structures of the study are being very complexed by the Kabaw Thrust and the Sagaing Fault. The major structural trend mainly a N–S direction is covered by various faults trending NE–SW. The movement and the deformation along the Sagaing Fault (N-S trend) is affected on the later stage of mineralization which is evidenced by a late-stage quartz vein networks which are aligned along the faults. The geological map of the Banmauk-Wuntho district is shown in figure 2.

A number of orebodies are being mined around Bamauk area. Legyin, Myauk Let Sho, EE3, Thapan Aing and Khambart and Legyin are referred to as deposits. This research focuses on the Legyin gold deposit. Nature of the gold mineralization in the Legyin prospect occurs as disseminations, massive veins and stockworks. As deposit geology, it is mainly composed of Mawgyi Andesite (Cretaceous), phyllite and mudstone (Shwedaung Formation, Upper Triassic age), sandstone (Wabochaung Formation, Miocene age) and granodiorite (Mesozoic and Paleogene). Figure 3 shows the deposit geological map and figure 4 shows the distribution of exposed lithologic units (Mawgyi andesite, granodiorite, phyllite, mudstone, sandstone and shale) and their outcrop nature and microscopic texture.

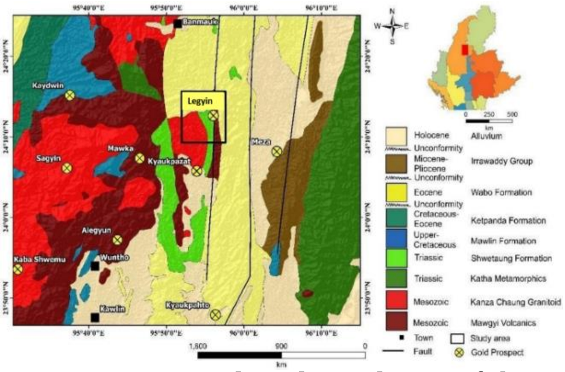



Figure 2. Regional geological map of the research area (modified after UNDP, 1978, 1979; Mitchell 2018

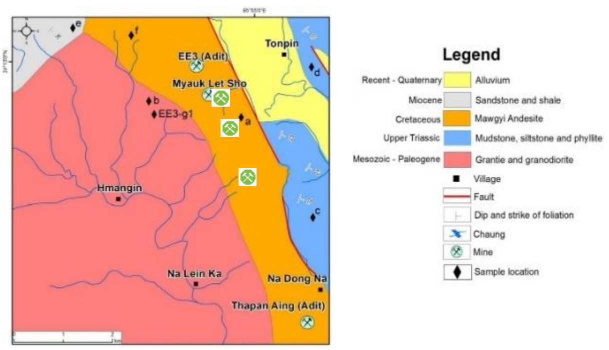



Figure 3. Deposit geological map of the research area (Modified after Htet et.al., 2021)

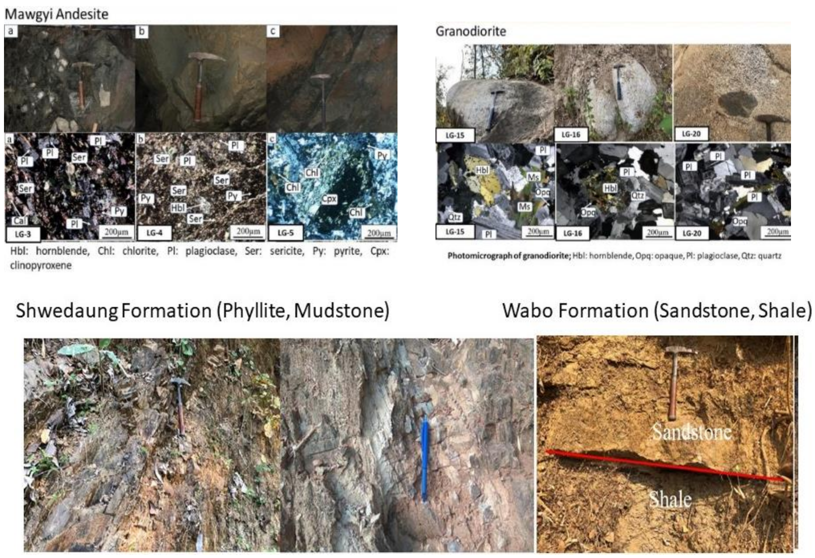



Figure 4. Outcrop nature and photomicrograph of Mawgyi andesite and granodiorite, and outcrop nature of phyllite, mudstone, sandstone and shale

## 4. Whole Rock Chemical Analysis (X-ray Fluorescence)

Twenty samples from the Legyin gold deposit were selected for whole-rock composition analysis including fresh and hydrothermally altered Mawgyi andesite unit. The whole rock chemical analyses (XRF) are listed in Table 1.

Table 1. Major and trace elements analysis of Mawgyi Andesite

| Sample Name | LG-1 | LG-5 | LG-10 | LG-12 | LG-16 | LG-17 | LG-18 | LG-19 | LG-20 | LG-21 | LG-22 | LG-24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock Type/ Alteration | Basaltic andesite | | Andesite | | Andesite | Basalt | | Basaltic andesite | Andesite | | Andesite | |
| $SiO_2$ wt% | 50.85 | 47.38 | 52.36 | 54.36 | 55.56 | 47.85 | 49.35 | 58.68 | 45.42 | 55.56 | 45.83 | 50.41 |
| $TiO_2$ | 2.24 | 1.90 | 1.39 | 0.77 | 1.03 | 1.83 | 0.26 | 1.34 | 1.32 | 0.60 | 0.83 | 1.45 |
| $Al_2O_3$ | 12.62 | 14.67 | 13.12 | 14.48 | 14.40 | 13.53 | 7.45 | 8.84 | 14.99 | 7.83 | 17.86 | 12.92 |
| FeO | 13.08 | 10.23 | 8.99 | 11.07 | 5.24 | 10.03 | 6.43 | 7.10 | 9.59 | 5.48 | 12.34 | 7.67 |
| MnO | 0.17 | 0.19 | 0.17 | 0.21 | 0.09 | 0.18 | 0.11 | 0.13 | 0.17 | 0.20 | 0.20 | 0.15 |
| MgO | 3.85 | 0.91 | 5.01 | 5.74 | 2.67 | 4.46 | 0.76 | 3.87 | 5.67 | 3.32 | 6.83 | 3.16 |
| CaO | 8.79 | 18.19 | 12.65 | 9.63 | 10.01 | 11.10 | 24.62 | 14.20 | 9.54 | 15.22 | 8.22 | 14.05 |
| $Na_2O$ | 2.35 | 0.51 | 1.08 | 1.90 | 3.23 | 3.02 | 0.58 | 0.69 | 1.69 | 1.54 | 1.94 | 2.97 |
| $K_2O$ | 0.34 | 0.08 | 1.01 | 1.26 | 1.18 | 0.31 | 0.11 | 0.49 | 1.82 | 0.29 | 1.90 | 0.31 |
| $P_2O_5$ | 0.56 | 0.40 | 0.29 | 0.11 | 0.11 | 0.26 | 0.04 | 0.21 | 0.19 | 0.10 | 0.12 | 0.28 |
| LOI | 3.06 | 2.28 | 5.77 | 2.33 | 6.38 | 5.22 | 10.40 | 5.31 | 8.57 | 10.90 | 4.68 | 6.42 |
| Total | 99.84 | 99.85 | 99.86 | 99.84 | 99.95 | 99.89 | 99.88 | 99.92 | 98.86 | 99.92 | 99.85 | 99.90 |
| S (ppm) | 132 | 82 | 382 | 367 | 145 | 156 | 162 | 186 | 261 | 321 | 148 | 126 |
| V | 388 | 376 | 215 | 307 | 178 | 286 | 178 | 250 | 325 | 120 | 388 | 265 |
| Cr | 15 | 22 | 13 | 116 | 32 | 79 | n. d | 62 | 93 | 16 | 119 | 96 |
| Co | 41 | 9 | 66 | 57 | 40 | 60 | 27 | 25 | 49 | 40 | 31 | 32 |
| Ni | 35 | 12 | 17 | 40 | 31 | 85 | 12 | 35 | 51 | 32 | 43 | 51 |
| Cu | 4 | 21 | 9 | 163 | 6 | 11 | 3 | 39 | 26 | 16 | 61 | 12 |
| Zn | 164 | 8 | 121 | 86 | 43 | 114 | n. d | 68 | 76 | 43 | 98 | 68 |
| Pb | n. d | n. d | 29 | 2 | n. d | 3 | n. d | n. d | n. d | n. d | 1 | 2 |
| As | n. d | n. d | 2 | n. d | n. d | n. d | n. d | n. d | n. d | n. d | n. d | n. d |
| Mo | n. d | 1 | 2 | n. d | n. d | n. d | n. d | n. d | n. d | n. d | n. d | n. d |
| Rb | 5 | 1 | 17 | 24 | 21 | 7 | 1 | 10 | 36 | 6 | 35 | 6 |
| Sr | 86 | 704 | 443 | 220 | 132 | 121 | 265 | 85 | 156 | 52 | 283 | 109 |
| Ba | 51 | n. d | 46 | 104 | 95 | 41 | n. d | 6 | 144 | 11 | 241 | 48 |
| Y | 69 | 67 | 51 | 24 | 24 | 49 | 16 | 36 | 36 | 20 | 30 | 45 |
| Zr | 243 | 255 | 134 | 46 | 75 | 146 | 32 | 120 | 101 | 66 | 56 | 128 |
| Nb | 9 | 8 | 7 | 2 | 2 | 5 | 2 | 4 | 5 | 3 | 3 | 6 |

*Abbreviation: C-C-A: chlorite-carbonate-alteration, E-C-A: epidote-calcite±albite- alteration, S-C-A: sericite-carbonate-alteration, n.d: not detected*

## 5. Hydrothermal Alteration

The type of hydrothermal alteration from the Legyin gold deposit is classified as chlorite-carbonate alteration, sericite-carbonate alteration, and epidote-carbonate ± albite alteration.

## 6. Ore Mineralogy and Paragenesis

Massive quartz-sulfide vein, stockwork, dissemination and veinlets are mineralization nature in the Legyin prospect. By the ore mineralogy and the cross-cutting relationship, massive quartz-carbonated-sulfide veins and quartz-carbonate were identified. Gold-bearing quartz veins occur along the fault and breccia zones. The most abundant sulphide ore mineral is pyrite, which is associated with the minor amounts of chalcopyrite and sphalerite. Chalcopyrite coexists with native gold. Native gold and chalcopyrite are filling in the fissure of pyrite crystals. Telluride is confined with the gold-bearing quartz veins which coexists with pyrite, chalcopyrite, magnetite, calaverite and quartz. It occurs as inclusions in chalcopyrite. Petzite occurs as inclusions in chalcopyrite. The most abundant gold-bearing telluride mineral is calverite. It also occurs as inclusions in pyrite (Figure 8).

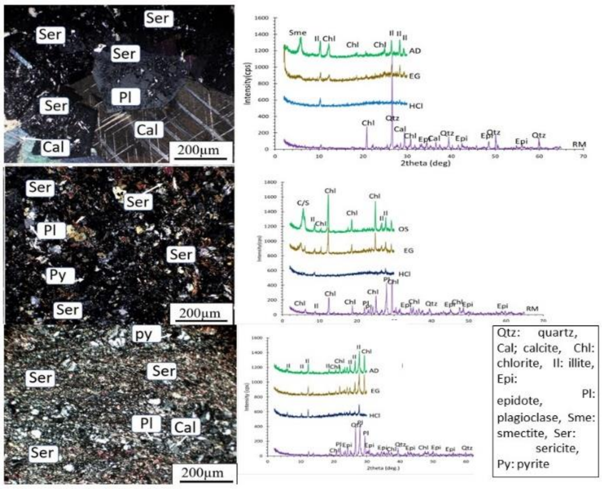
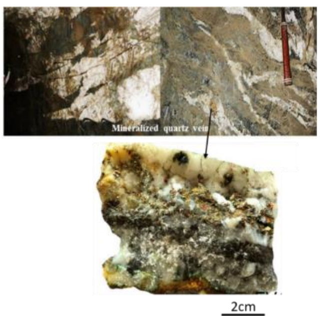
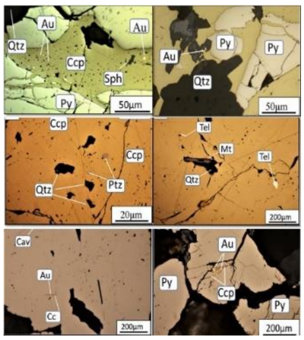



Figure 5. Photomicrograph of alteration minerals and XRD results. (Abbreviation: Cal=calcite, Chl=chlorite, Pl=plagioclase, Py=pyrite, Qtz=quartz, Ser=sericite)

Based on the ore and gangue mineral assemblages, three mineralization stages are recognized at the Legyin gold prospect: (1) Stage-I, quartz-carbonate-sulfide main veins, (2) Stage-II, E-W trending veins that crossed-cut the Stage-I main veins, and (3) Stage-III parallel to the Stage-I main veins. Stage-I veins comprise pyrite, pyrrhotite, chalcopyrite, sphalerite, magnetite, electrum and native gold. The gold mineralization is not associated with the Stage-II veins. Stage-III veins are characterized by tellurobismuthite, calaverite and petzite. Native gold and magnetite is associated with pyrite, chalcopyrite. The paragenetic diagram is shown in figure 9.




*Abbreviation: Au= native gold, Ccp=chalcopyrite, Py=pyrite, Qtz=quartz, Sph=sphalerite*

Figure 7. Nature of mineralized quartz vein and veinlets and specimen of ore sample

Figure 8. Photomicrograph of ore minerals and their texture from the Legyin prospect. (Native gold associated with chalcopyrite and sphalerite,)

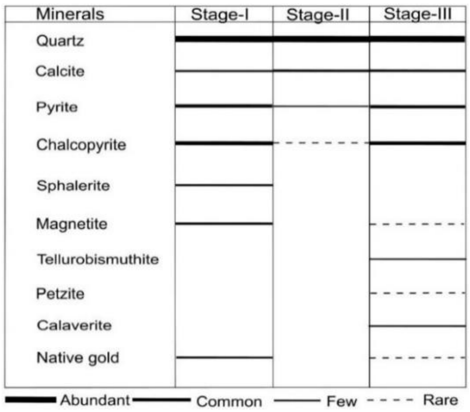



Figure 9. Paragenetic sequence of mineralized quartz vein in the Legyin prospect

Ten ore samples were analyzed by Atomic Absorption Spectrum (AAS) analysis method and the assay results show the potential of gold range from 0.1 to 2.6ppm.

Table 2. Atomic Absorption Spectrum (AAS) Analysis

| No. | Sample | Au | Ag | Sb | As | Hg | Cu | Zn | Pb |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 052B | 0.71 | 0.05 | na | na | na | 40.7 | 53.08 | 47.89 |
| 2 | 053B | 0.71 | 0.06 | na | na | na | 10.6 | 51.83 | 36.6 |
| 3 | 054B | 0.53 | 0.33 | na | na | na | 78.68 | 15.79 | 56.36 |
| 4 | 055B | 0.08 | 0.12 | na | na | na | 68.93 | 14.07 | 44.3 |
| 5 | 056B | 0.1 | 0.3 | na | na | na | 43.11 | 94.89 | 150.7 |
| 6 | 057B | 0.04 | 0.1 | na | na | na | 11.41 | 38.85 | 50.91 |
| 7 | 058B | 0.69 | 6.12 | na | na | na | 12.22 | 85.59 | 40.19 |
| 8 | 059B | 17 | 0.06 | na | na | na | 63.73 | 61.77 | 35.51 |
| 9 | 060B | 2.82 | 0.07 | na | na | na | 47.65 | 66.31 | 34.08 |
| 10 | 061B | 0.71 | 0.06 | na | na | na | 9.36 | 33.22 | 40.02 |
| 11 | 062B | 3.57 | 0.07 | na | na | na | 13.61 | 87.06 | 36.63 |
| 12 | 063B | 0.7 | 0.06 | na | na | na | 37.38 | 53.56 | 46.15 |
| 13 | 064B | 0.69 | 0.01 | na | na | na | 45.96 | 30.76 | 40.02 |
| 14 | 065B | 0.7 | 0.21 | na | na | na | 39.94 | 22.43 | 34.01 |
| 15 | 066B | 0.12 | 0.08 | na | na | na | 78.68 | 80.09 | 45.88 |
| 16 | 070B | 0.7 | 0.01 | na | na | na | 14.17 | 46.9 | 39.98 |
| 17 | 071B | 0.01 | 0.04 | na | na | na | 79.07 | 40.28 | 33.84 |
| 18 | 072B | 0.01 | 0.01 | na | na | na | 7.93 | 21.7 | 53.2 |
| 19 | 073B | 0.01 | 0.01 | na | na | na | 4.06 | 21.34 | 58.19 |
| 20 | 074B | 0.7 | 0.06 | na | na | na | 127.73 | 43.73 | 47.24 |

## 7. Fluid Inclusion Study

One hundred fluid inclusions from five quartz samples were measured for fluid inclusions study. According to Roedder (1984), the petrography of fluid inclusions is classified as primary and secondary origins (Figure 10). The fluid inclusions aligned with growth zones in solitary crystals were identified as primary inclusions and the secondary fluid inclusions occur as transangular healed fractures. Only primary fluid inclusions were measured in this study. Various shapes and size of fluid inclusions are observed under microscope: spheroidal, irregular, rounded, polygonal, elongated and sub-rounded. The size of fluid inclusions varies from 5 µm to 20 µm. Three types of fluid inclusions were characterized as: Type A - two phases liquid (L) + vapor (V) inclusions (liquid-dominated); Type B - two phases vapor + liquid inclusions (vapordominated); and Type C - three phases, aqueous liquid + carbonic liquid + carbonic vapor inclusions.

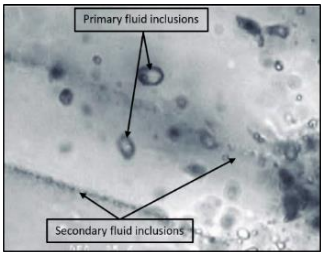



Figure 10. Photomicrograph of primary and secondary fluid inclusions

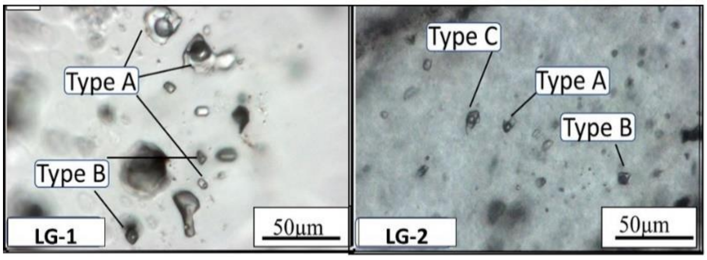



Figure 11. Photomicrograph of three types of fluid inclusions

Fluid inclusions Microthermometry

The result of fluid inclusion microthermometry is summarized in table 3. The trapping temperatures of hydrothermal fluid in the quartz veins are around 180 °C, 176 °C and 158 °C with the low salinity 0.3 to 9.5 Wt% NaCl equiv. The estimated formation depth is 300m, 280m and 220m respectively. The deposition of ore is formed by the decrease in pressure and fluid immiscibility of the ore fluids.

Table 3 Summary of fluid inclusion types and measured micro thermometric data of the fluid inclusions in the Legyin prospect

| Sample No | Veins Type | Type | $T_m$-$CO_2$ (°C) | Tm-cla (°C) | $T_h$-$CO_2$ (°C) | $T_h$ (°C) | $T_m$-ice (°C) | Salinity | FI (N) |
|---|---|---|---|---|---|---|---|---|---|
| LG-1 | Quartz vein | Two-phase Type A | | | | 265- 360 | -0.2 to -5.6 | 0.3 to 8.7 | 20 |
| | | Two-phase Type B | | | | 350-420 | -0.2 to -3.8 | 0.4 to 6.2 | 10 |
| | | Three-phase Type C | -56 to -58 | 5.0 to 8.5 | 26.1 to 30.1 | 230-365 | | 1.1 to 7.5 | 10 |
| LG-2 | Quartz vein | Two-phase Type A | | | | 180-260 | -0.5 to -6.5 | 0.8 to 9.5 | 9 |
| | | Two-phase Type B | | | | 315-346 | -1.6 to -4.0 | 2.5 to 6.4 | 5 |
| | | Three-phase Type C | -56 to -58 | 5.8 to 7.9 | 28.0 to 30.6 | 280-310 | | 3.1 to 8.7 | 7 |
| LG-3 | Quartz vein | Two-phase Type A | | | | 176-387 | -0.9 to -5.7 | 1.7 to 8.8 | 15 |
| | | Two-phase Type B | | | | 292-436 | -2.1 to 7.5 | 3.5 to 10.1 | 15 |
| LG-4 | Quartz vein | Two-phase Type A | | | | 200-320 | -1.5 to -5.0 | 2.6 to 7.9 | 10 |
| | | Two-phase Type B | | | | 287-425 | -2.4 to -6.7 | 4.3 to 9.5 | 9 |
| LG-5 | Quartz vein | Two-phase Type A | | | | 196-340 | -0.3 to -5.9 | 0.5 to 9.1 | 15 |
| | | Two-phase Type B | | | | 290-450 | -0.7 to -6.6 | 1.2 to 9.8 | 12 |
| LG-6 | Quartz vein | Two-phase Type A | | | | 158-313 | -3.8 to -7.2 | 6.2 to 10.5 | 12 |

*Notes: Tm-$CO_2$= melting temperature of $CO_2$; $T_{m-cla}$= melting temperature of $CO_2$clathrate; $T_h$-$CO_2$= partial homogenization of $CO_2$ inclusions; $T_h$= Total homogenizationtemperature of inclusions; Tm-ice= final ice melting temperature; N= total number of fluid inclusions*

## 8. Conclusion

Legyin gold deposit is one of the famous gold deposits in Bamauk Township, Sagaing Region, Myanmar. According to the field investigation, megascopic and microscopic study, the composed rock units can be classified as andesite, phyllite, mudstone (Shwedaung Formation) and sandstone (Wabo Chaung Formation) and granodiorite. Based on the microscopic study, ED-XRF and XRD analyses, and the alteration mineral assemblages, three kinds of alteration zones were recognized as sericite-carbonate alteration, epidote-calcite±albite alteration and chlorite-carbonate alteration zones. Atomic Absorption Spectrum (AAS) results show the potential of gold range from 0.1 to 2.6ppm. The fluid inclusion data show that the trapping temperatures of hydrothermal fluid in the quartz veins are around 180 °C, 176 °C and 158 °C with the low salinity 0.3 to 9.5 Wt% NaCl equiv., and the estimated formation depth is 300m, 280m and 220m respectively. On the basis of the geology, ore mineral paragenesis and alteration mineral assemblages, the type of gold mineralization in the Legyin area can be suggested as the epithermal-type deposit.

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