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Origin and Ore-Forming Mechanism of Tin-Tungsten Mineralization at the Tagu Area, Myeik, Southern Myanmar: Constraints from Fluid Inclusion and Ore Mineralogy Studies

Dr. Kyaw Thu Htun, Manager, No.2 Mining Enterprise
Dr. Kotaro Yonezu, Associate Professor, Kyushu University, Japan
Dr. Aung Zaw Myint, Professor, Yangon University, Myanmar
Dr. Thomas Tindell, Assistant Professor, Kyushu University, Japan
Dr. Koichiro Watanabe, Professor, Kyushu University, Japan

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Dr. Kyaw Thu Htun, Manager (Geology)

No. 2 Mining Enterprise

Abstract

This paper attempts to provide new insights into Sn-W ore-forming mechanism of Tagu deposit. Mineralized veins consist of early-formed oxide ore minerals, such as cassiterite and wolframite, which were followed by the formation of sulfide minerals. Three main types of fluid inclusions were distinguished from the mineralized quartz veins hosted by granite and metasedimentary rocks: Type-A—two phases, liquid (L) + vapor (V) aqueous inclusions; Type-B—two phases, vapor (V) + liquid (L) vapor-rich inclusions; and type-C—three phases, liquid + CO_2-liquid + CO_2-vapor inclusions. The homogenization temperatures of type-A inclusions range from 140 oC to 330°C (mode at 230°C), with corresponding salinities from 1.1 wt.% to 8.9 wt.% NaCl equivalent for quartz veins hosted in metasedimentary rocks, and from 230°C to 370°C (mode at 280°C), with corresponding salinities from 2.9 wt.% to10.6 wt.% NaCl equivalents for quartz veins hosted in granite. The homogenization temperatures of type-B vapor-rich inclusions in quartz veins in granite range from 310°C to 390°C (mode at 350°C), with corresponding salinities from 6.7 wt.% to 12.2 wt.% NaCl equivalent. The homogenization temperatures of type-C H_2O–CO_2–NaCl inclusions vary from 270°C to 405°C (mode at 330°C), with corresponding salinities from 1.8 wt.% to 5.6 wt.% NaCl equivalent. The main ore-forming mechanisms of the Tagu Sn–W deposit are characterized by fluid immiscibility during an early stage, and fluid mixing with meteoric water in the late stage at a lower temperature.

Keywords: *Sn–W mineralization; fluid inclusions; immiscibility*

မြန်မာနိုင်ငံတောင်ပိုင်း၊ မြိတ်ခရိုင်၊ တဂူဒေသရှိ ခဲမဖြူ-အဖြိုက် သတ္တုသိုက်ဖြစ်ထွန်းမှု၏ မူလအစနှင့် သတ္တုသိုက် ဖြစ်ပေါ်မှု ဖြစ်စဉ်များကို အရည်ပါဝင်မှုနှင့် သတ္တုတွင်းထွက်ဆိုင်ရာ လေ့လာခြင်းမှတစ်ဆင့် လေ့လာသုံးသပ်ခြင်း

ဒေါက်တာကျော်သူထွန်း၊ မန်နေဂျာ (ဘူမိဗေဒ)
အမှတ် (၂) သတ္တုတွင်းလုပ်ငန်း

စာတမ်းအကျဉ်း

တဂူသတ္တုတွင်းရှိ ခဲမဖြူ၊ အဖြိုက်နက်သတ္တုရိုင်းများမှာ သတ္တုရိုင်းပါသလင်းကြော များ တွင် အောက်ဆိုက်ဒ်တွင်းထွက်များအနေဖြင့်တွေ့ရှိရသည့် ခဲမဖြူ၊ အဖြိုက်နက် ကဲ့သို့ သော သတ္တုရိုင်းများက အစောဆုံးစွဲဝင်ဖြစ်တည်ထားပြီး၊ ၎င်းတို့နောက်မှ သာဆာလဖိုက်ဒ် သတ္တု များ ဖြစ်တည်လာခဲ့ပါသည်။ တဂူ ခဲမဖြူ၊ အဖြိုက်နက်သတ္တုတွင်းရှိ အရည်ပါဝင်မှုအား အမျိုး အစား (၃) မျိုး အနေဖြင့်တွေ့ရှိရပါသည်။ ၎င်းတို့မှာ အရည်နှင့်အငွေ့ အမျိုးအစား ဖြစ်သည့် liquid(L) + vapor (V) aqueous inclusions အား အမျိုးအစား (က)၊ အငွေ့ဓာတ်ပိုများ သော အငွေ့ နှင့် အရည် အမျိုးအစား ဖြစ်သည့် vapor (V) + liquid (L) vapor-rich inclusions အား အမျိုးအစား (ခ) နှင့် အရည်-ကာဗွန်ဒိုင် အောက်ဆိုဒ် အရည်-ကာဗွန်ဒိုင်အောက်ဆိုဒ်အငွေ့ အမျိုးအစား ဖြစ်သည့် liquid+CO_2-liquid+ CO_2 -vapor inclusions အား အမျိုအစား (ဂ) တို့ဖြစ် ပါသည်။ အနည်ကျ အသွင်ပြောင်းကျောက်များတွင် တည်ရှိသော သလင်းကြော (quartz veins) များမှ အမျိုး အစား (က)၏ တစ်သားတည်းဖြစ်ခြင်း အပူချိန်များသည် ၁၄ဝ ဒီဂရီစင်တီ ဂရိတ်မှ ၃၃ဝ ဒီဂရီ စင်တီ ဂရိတ် (mode at ၂၃ဝ ဒီဂရီစင်တီ ဂရိတ်) အထိရှိပြီး၊ ဆားငန်ဓာတ် ပါဝင်မှုမှာ ၁.၁ wt.% မှ ၈.၉ wt.% NaCl ဖြစ်ပြီး နှမ်းဖတ် ကျောက် (Granite) တွင်တည်ရှိသော quartz veins များမှ အမျိုး အစား (က) ၏ တစ်သားတည်း ဖြစ်ခြင်း အပူချိန်များသည် ၂၃ဝ ဒီဂရီ စင်တီ ဂရိတ်မှ ၃၇ဝ ဒီဂရီ စင်တီဂရိတ်မ (mode at ၂၈ဝ ဒီဂရီစင်တီဂရိတ်) အထိရှိပြီး ဆားငန်ဓာတ် ပါဝင်မှုမှာ ၂.၉ wt.% မှ ၁၀.၆ wt.% NaCl ဖြစ်သည်ကို တွေ့ရှိရပါသည်။ နှမ်းဖတ် ကျောက် (Granite) တွင်တည်ရှိ သော quartz veins များမှ အမျိုးအစား (ခ) ၏ တစ်သားတည်း ဖြစ်ခြင်း အပူချိန် များသည် ၃၁ဝ ဒီဂရီစင်တီဂရိတ်မှ ၃၉ဝ ဒီဂရီစင်တီဂရိတ်မ (mode at ၃၅ဝ ဒီဂရီစင်တီဂရိတ်) အထိရှိပြီး ဆားငန်ဓာတ်ပါဝင်မှုမှာ ၆.၇ wt.% မှ ၁၂.၂ wt.% NaCl ဖြစ်သည်ကို တွေ့ရှိရပါသည်။ အမျိုးအစား (ဂ)၏ တစ်သားတည်းဖြစ်ခြင်း အပူချိန်များသည် ၂၇ဝ ဒီဂရီစင်တီ ဂရိတ်မှ ၄ဝ၅ ဒီဂရီ စင်တီ ဂရိတ်မ (mode at ၃၃ဝ ဒီဂရီစင်တီ ဂရိတ်) အထိရှိပြီး ဆားငန် ဓာတ် ပါဝင်မှုမှာ ၁.၈ wt.% မှ ၅.၆ wt.% NaCl ဖြစ်သည်ကို တွေ့ရှိရပါ သည်။ တဂူခဲမဖြူ၊ အဖြိုက် နက်သတ္တုသိုက်၏ အဓိကသတ္တုရိုင်း ဖြစ်တည်မှုဖြစ်စဉ်များမှာ အစောပိုင်းအဆင့်တွင် အရည် များ မရောနှောနိုင်ခြင်း (immiscibility) လက္ခဏာ ဖြစ်ပေါ်ပြီး နောက်ပိုင်းအဆင့်တွင် အပူချိန်နိမ့် သော အခြေ အနေတွင် မိုးရေနှင့်အရည်များ ရောနှောခြင်း တို့ဖြင့် သတ္တုသိုက် တစ်ခု ဖြစ်လာသည်ကို လေ့လာ တွေ့ရှိရပါသည်။

Origin and Ore-Forming Mechanism of Tin-Tungsten Mineralization at the Tagu Area, Myeik, Southern Myanmar: Constraints from Fluid Inclusion and Ore Mineralogy Studies

1. Introduction

The majority of tin–tungsten deposits are situated in the Tanintharyi (Tennanserim) Region, especially in the Dawei (Tavoy) and Myeik (Mergui) districts, except the largest deposit at Mawchi (Kayah State). The Dawei district has the largest and more important tin–tungsten lode mines, whereas more tin-rich tin–tungsten lode mines, tin lode mines, and alluvial tin deposits are found in the Myeik district (Than Htun et al., 2017; Kyaw Thu Htun et al., 2019). The magmatic and hydrothermal activities related to the world's main W and Sn resource in granite-related W-Sn deposits are thought to have generated the formation of ore minerals in and associated peraluminous granitic plutons (Burnham, 1979; Candela, 1997; Audétat et al., 2000; Pirajno, 2009).

However, the nature and the origin of the ore-forming fluids appear to be variable and are still debated (e.g., Marignac and Cathelineau, 2009). The fluid inclusion assemblages of the Tagu tin–tungsten deposit are different from those of other well-known world class tin–tungsten deposits in Myanmar, such as Mawchi and Hermyingyi. The fluid inclusions in the Tagu tin-tungsten deposit are observed as H_2O-CO_2-NaCl fluid system, whereas only H_2O-NaCl system are found in other tin–tungsten deposits in Myanmar such as well-known world class deposits Mawchi and Hermyingyi. In this study, ore forming process will be formulated based on fluid inclusion study and discuss the ore-forming conditions and mechanism of ore deposition.

1.1 Regional Geology

The granites in the Mergui area form into three distinct ranges such as the eastern frontier range along the Myanmar-Thai border, the central range, and the western (coastal) range (Figure.1). They are largely elongated bodies parallel to the NNW–SSE trend of the metasedimentary units (Mergui Group). The important primary Sn–W mines such as Hermyingyi, Wagone, Bawapin, Pagaye, Tagu and the tin placer deposit at Heinda are located in the Central Range (Bender, 1983; Myint et al., 2014; Li et al., 2018; Kyaw Thu Htun et al., 2019).

In the eastern frontier Myanmar-Thai border regions, hornblende-bearing granitoids appear to be older, whereas younger W-Sn bearing biotite-muscovite granitoids at the central and younger intrusive rocks are observed in the western coastal region in the Mergui area. The intrusive rocks in the Mergui area are are affected by regional greenschist to lower amphibolite facies metamorphism but appear that the contact metamorphic aureoles are not so substantially form over a large area.

The Mergui plutons are notably related with Sn-W bearing quartz veins with greisen borders, and pegmatites, and medium-grained biotite granite appears to be a more favourable to host the Sn-W mineralization than the coarse-grained porphyritic and hornblende bearing granitoids. Biotite granites together with two mica (biotite and muscovite) granites are the most common rock types with a minor amount of porphyritic biotite granites (Khin Zaw, 1990).

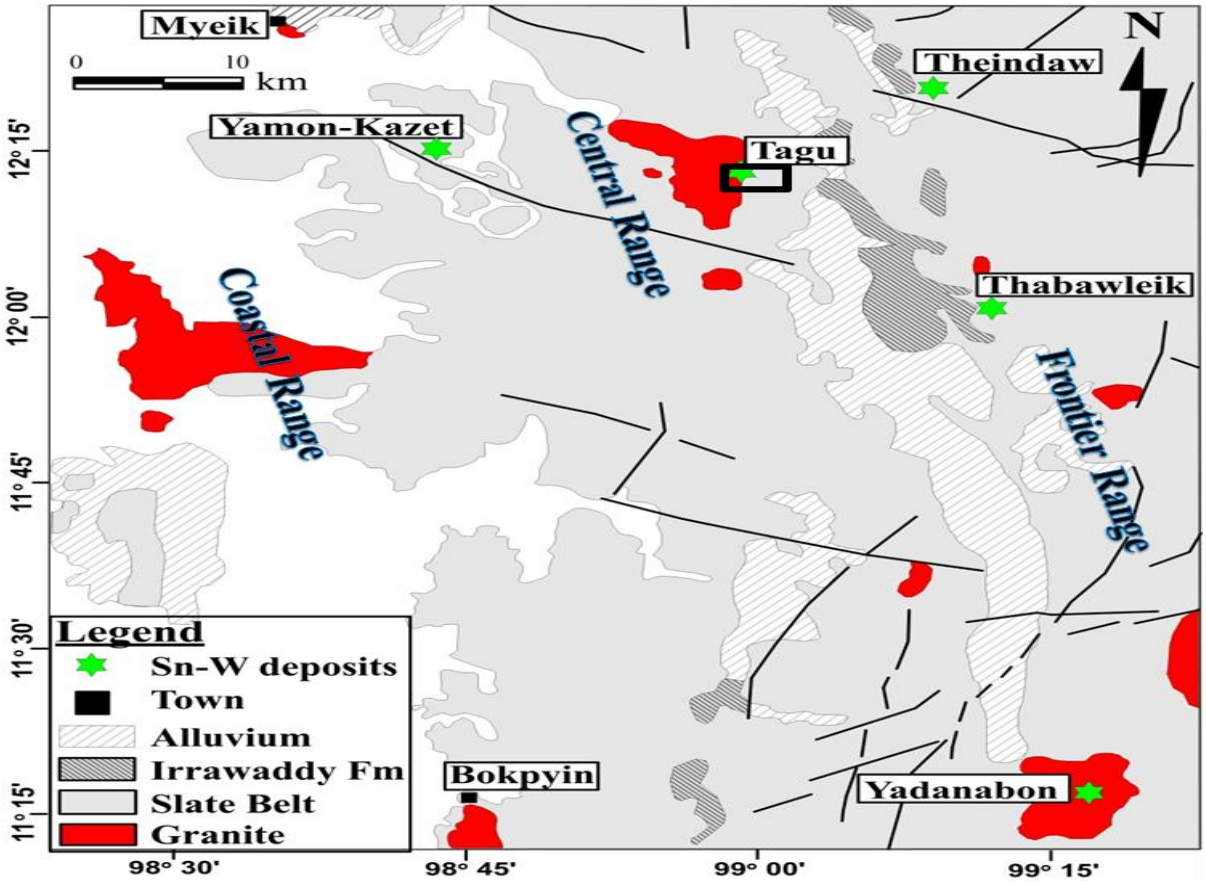


Figure.1. Regional geology of Mergui District, Southern Myanmar (modified after Aung Zaw Myint, 2016).

1.2 Deposit Geology

The Tagu tin–tungsten deposit, situated approximately 45 km to the southeast of the Myeik City and 15 km to the north-northwest of Tanintharyi town, is one of the largest tin–tungsten deposits in the Myeik area (Figure 2). In this area, the mineralized quartz veins are hosted by both metasedimentary rocks (Mergui Group) and intrusive igneous rocks (granitic rocks), which are the main lithologic units of the study area. The country rocks (metasedimentary rocks) are structurally deformed and greenschist to upper amphibolite facies ranging in age as early as Upper Proterozoic to Upper Paleozoic and locally of fossiliferous, metaclastic rocks (Mid Jurassic to Lower Cretaceous) (Khin Zaw, 1990). Elongated granite plutons are emplaced along NNW–SSE trend, the regional strike of the Mergui Group. More than 30 mineralized quartz veins have been discovered in the metasedimentary rocks which are discordant to the direction of the host rocks, while massive quartz vein with 1 m to more than 5 m across are found only in the granite body. Most mineralized quartz veins, parallel to each other, trend nearly E–W in the metasedimentary rocks dipping steeply to the southeast direction.

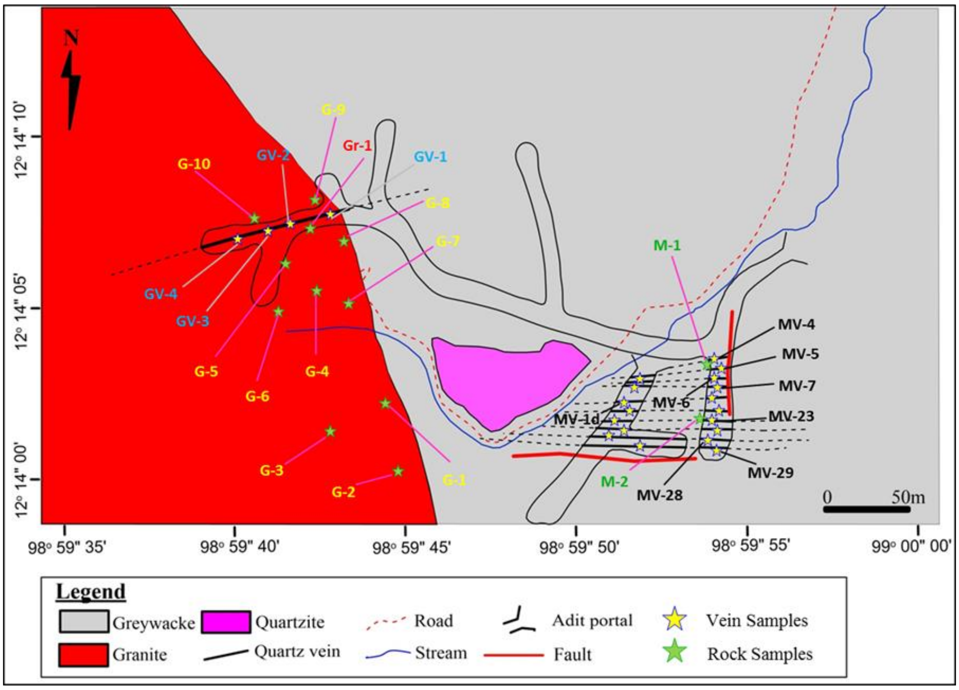


Figure.2. Geological map with sample locations of the Tagu mine area (modified after Tagu mine project map).

2. Objectives

The primary objectives of this research project are as follows:

(a) To constrain the paragenetic sequence of mineralization at the Tagu Area based on ore microscopic studies.

(b) To figure out the characteristics of ore forming mechanism of the Tagu Sn-W deposit based on fluid inclusion studies.

3. Materials and Methods

Fluid inclusion microthermometry on doubly polished sections was conducted at the Department of Earth Resources Engineering, Kyushu University, Japan. Microthermometric analyses were carried out using a Linkam LK600 heating–freezing stage with a Nikon Y-IM microscope. The errors for the temperature of measurements are ±0.5, ±0.2 and ±2.0ºC for runs in the range of -120 to -70ºC, -70 to 100ºC, and 100 to 600ºC, respectively. The final ice-melting temperatures were measured at the heating rate of less than 0.1ºC/min and the homogenization temperatures at the rate of ≤1ºC/min. Total salinities for NaCl-H_2O fluid inclusions were calculated from the final ice melting temperatures by using the equation of wt% NaCl= 1.78 T - 0.0442 T2 + 0.000557 T3 where T is depression temperature in ºC (Bodnar 1993), and are expressed as wt. % NaCl equivalent. The salinities of the CO_2–H_2O inclusions were calculated from the melting temperature of clathrate using the equation wt% NaCl= 15.52022 – 1.02342T – 0.05286T2 where T is the clathrate melting temperature expressed in ºC (Bozzo et al., 1973; Collins, 1979).

4. Results

4.1 Ore Mineralogy

The three ore formation stages are characterized by oxide ore stage, sulfide stage, and supergene stage in the Tagu tin–tungsten deposit. Early formed minerals are characterized by major oxide ore minerals, such as cassiterite and wolframite, followed by sulfide minerals. In the oxide ore stage, the deposition of wolframite appears somewhat later than cassiterite. Cassiterite occurs as idiomorphic crystals as well as mixed with wolframite. Most cassiterites are deformed and replaced by wolframite and sulfide minerals, such as sphalerite and chalcopyrite (Figures 3A, B). Some sulfide minerals fill the fracture within the cassiterite and wolframite (Figure 3C). This suggests that cassiterite and wolfram mite were formed earlier than the other sulfide minerals. Most sulfide minerals from the sulfide-bearing vein coexist with mutual intergrowth (Figure 3D). Covellite from the sulfide-bearing vein replaced the rims of chalcopyrite along the grain boundaries.

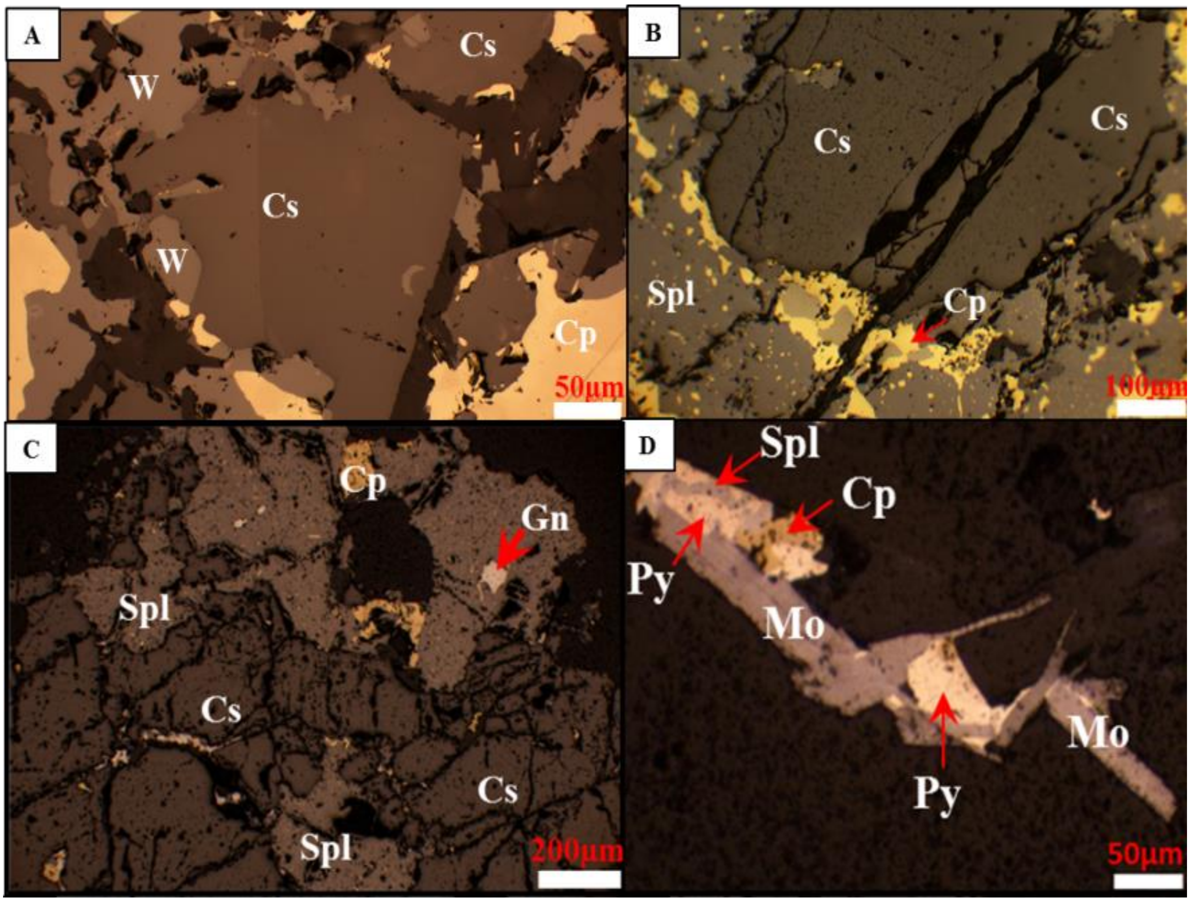


Figure.3. Photomicrographs of Sn-W ore specimen. A. Cassiterite replaced by wolframite associated with chalcopyrite. B. Cassiterite replaced by sphalerite with chalcopyrite blebs. C. Sphalerite with chalcopyrite blebs replacing between the fracture of cassiterite. D. Molybdenite associated with other sulfide minerals.

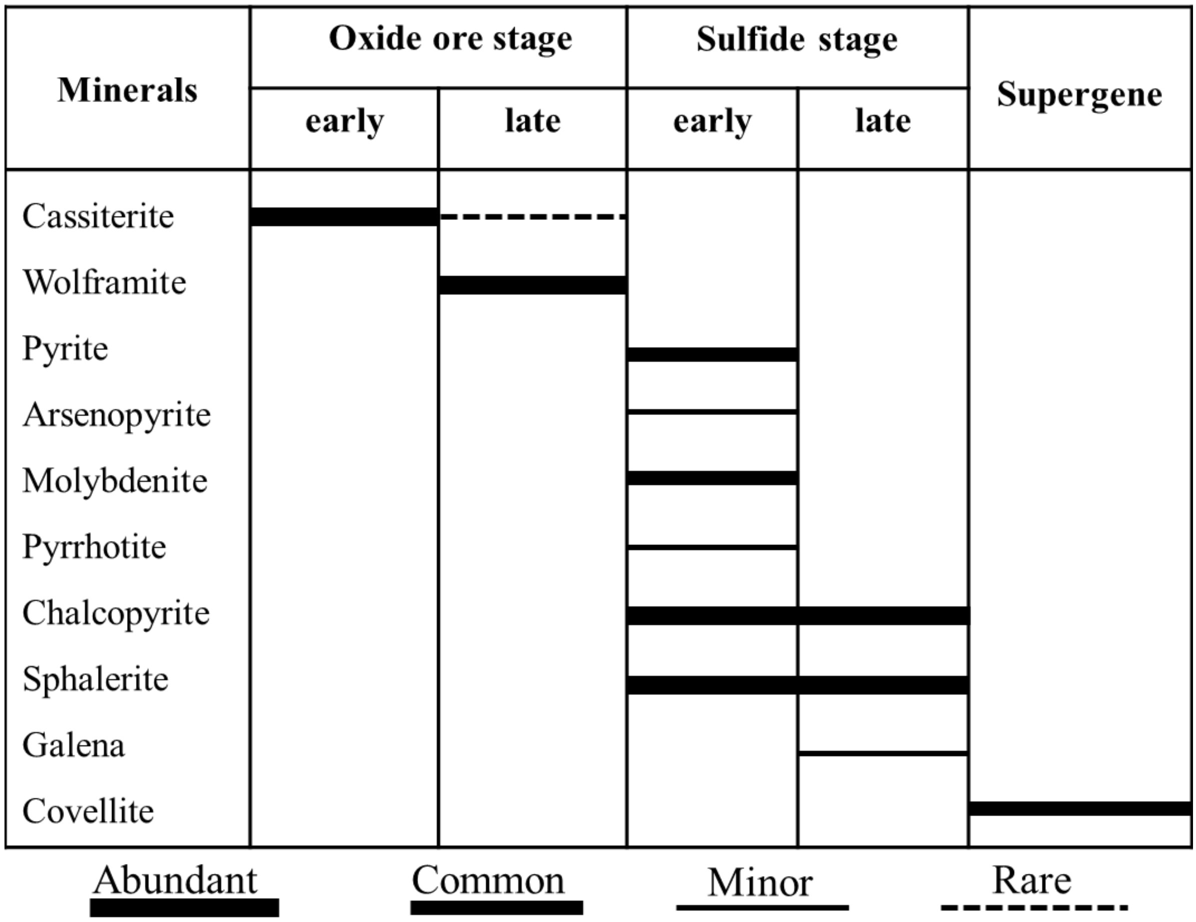


Figure.4. Paragenetic sequence of ore mineralization of the Tagu Sn-W deposit, southern Myanmar.

4.2 Fluid inclusion petrography and microthermometric measurements

The homogenization temperatures of about 300 fluid inclusions in seven vein quartz samples were determined in this present study. The detailed microthermometric data are presented mainly for fluid inclusions in veined quartz, hosted in granite, and metasedimentary rocks. The distribution pattern, shape, size, and phase content of fluid inclusions within the quartz crystals were examined to determine the fluid inclusion types and to distinguish primary and secondary inclusions as described by Roedder (1984). The fluid inclusions are commonly distributed in clusters, in isolation and along growth zones, and are considered to be primary in origin. The shapes of fluid inclusions are variable, and they are spheroidal, irregular, polygonal, rounded, sub- rounded and elongated (Figures 5A-D). The size of fluid inclusions range from 5 µm to 30 µm in diameter. According to the phase relations observed at room temperature, fluid inclusions from the Tagu tin-tungsten deposit are classified into three types. Type-A: This type fluid inclusions are liquid-dominated two phase (L+V) inclusions (Figure 5A). Type B: This fluid inclusion type is vapor-dominated; two phase (V+L) inclusions (Figure 5C). Type-C: At room temperature these fluid inclusions consist of three phases, aqueous liquid + liquid CO_2+ vapor CO_2, with the volume of the CO_2 phase (liquid) varying widely from 60 vol % to 85 vol % (Figure 5D). The microthermometric data of type-A, type-B and type-C inclusions are listed in Table1.

For type-A inclusions, final ice melting temperatures (Tice) vary from -0.6 to -5.2°C, -1.8 to -4.5°C and -1.9 to -6.1°C for the vein MV-28, MV-23 and MV-4 respectively, and -2.0 to -7.1°C, -1.7 to -6.5°C, -2.6 to -5.9 °C and -1.8 to 5.3°C for vein GV-1, GV-2, GV-3 and GV-4 respectively, with corresponding salinities from 1.1 to 8.1, 3.1 to 7.2 and 3.2 to 9.3 wt. %

NaCl equivalent and 2.0 to 7.1, 2.9 to 9.9, 4.3 to 9.1 and 3.1 to 8.3 wt. % NaCl equivalent, respectively (Figures 6 B, D, F, H, J, L and N).

The homogenization temperatures of type-A fluid inclusions vary from 140°C to 250°C, 190° to 270°C and 210° to 330°C for the vein MV-28, MV-23 and MV-4, respectively and from 230° to 370°C, 230° to 340°C, 230° to 330°C and 180° to 300°C for veins GV-1, GV-2, GV-3 and GV-4, respectively (Figures 6 A, C, E, G, I, K and M).

For type-B vapor-rich fluid inclusions, these inclusions homogenized to the liquid phase from 320° to 350°C, 310° to 390°C and 350° to 380°C for vein GV-1, GV-2 and GV-3, respectively and their Tice range from -5.0 to -7.4°C, -4.2 to -8.4°C and -5.1 to -7.5°C, which corresponds to salinities from 7.9 to 11.0, 6.7 to 12.2 and 8.0 to 11.1 wt. % NaCl equivalent, respectively (Figures 6 I, J, K, L, M and N).

The CO_2 melting temperatures (Tm-CO_2) of CO_2-bearing inclusions mineralized quartz veins in granite range from -59.5°C to -56.8°C, -59.1°C to 57.2 and -58.8°C to -56.9°C for the vein GV-1, GV-2 and GV-3, respectively suggesting that the carbonic phase is dominated by CO_2 with only minor components of other volatiles such as CH_4 and N_2 (Zhichao Zou, 2017). The partial homogenization temperatures (Th-CO_2) of the CO_2 phase into the liquid phase range from 25.1°C to 31.1°C, 25.8°C to 30.8°C and 26.3°C to 30.9°C for the vein GV-1, GV-2 and GV-3, respectively (Table 1).

The Th-tot range from 330°C to 405°C, 310°C to 350°C and 270°C to 350°C for vein GV-1, GV-2 and GV-3, respectively. The clathrate melting temperatures (Tm-clath) of type-C fluid inclusions vary from 7.3°C to 9.1°C, 7.1°C to 8.9°C and 7.1°C to 8.6°C for vein GV-1, GV-2 and GV-3, respectively corresponding to salinities ranging from 1.8 to 5.2, 2.2 to 5.6 and 2.8 to 5.6 wt. % NaCl equivalent, respectively (Figures 6 I, J, K, L, M and N). The type-C, CO_2-bearing inclusions are marked by relatively high Th-tot and lower salinities, than the type-A liquid-rich inclusions and type-B, vapor-rich inclusions (Figure 7).

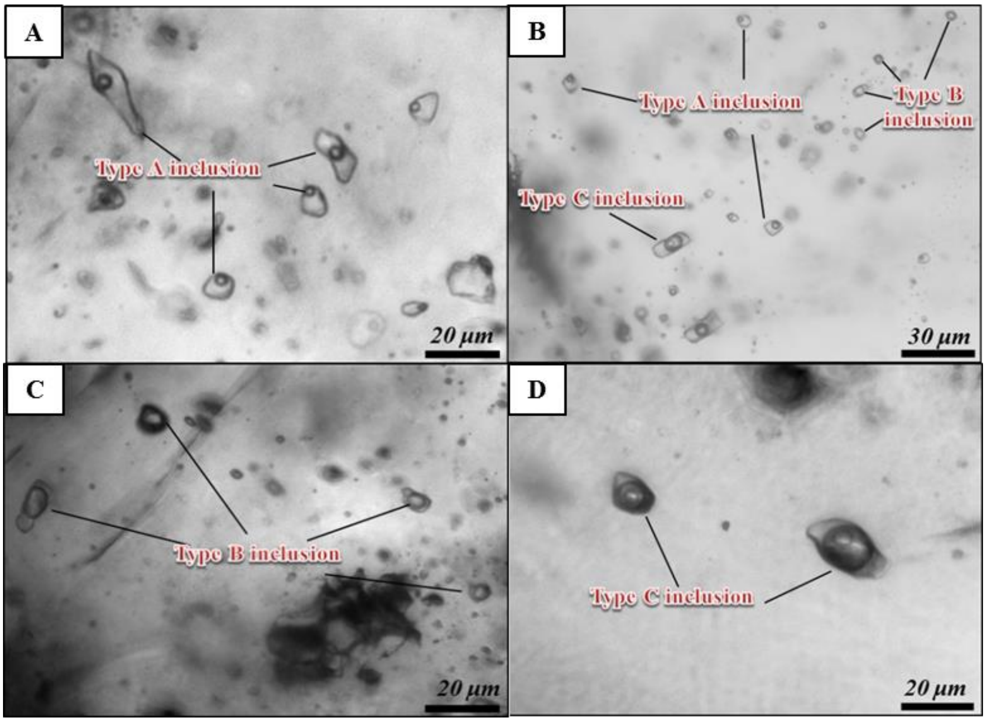
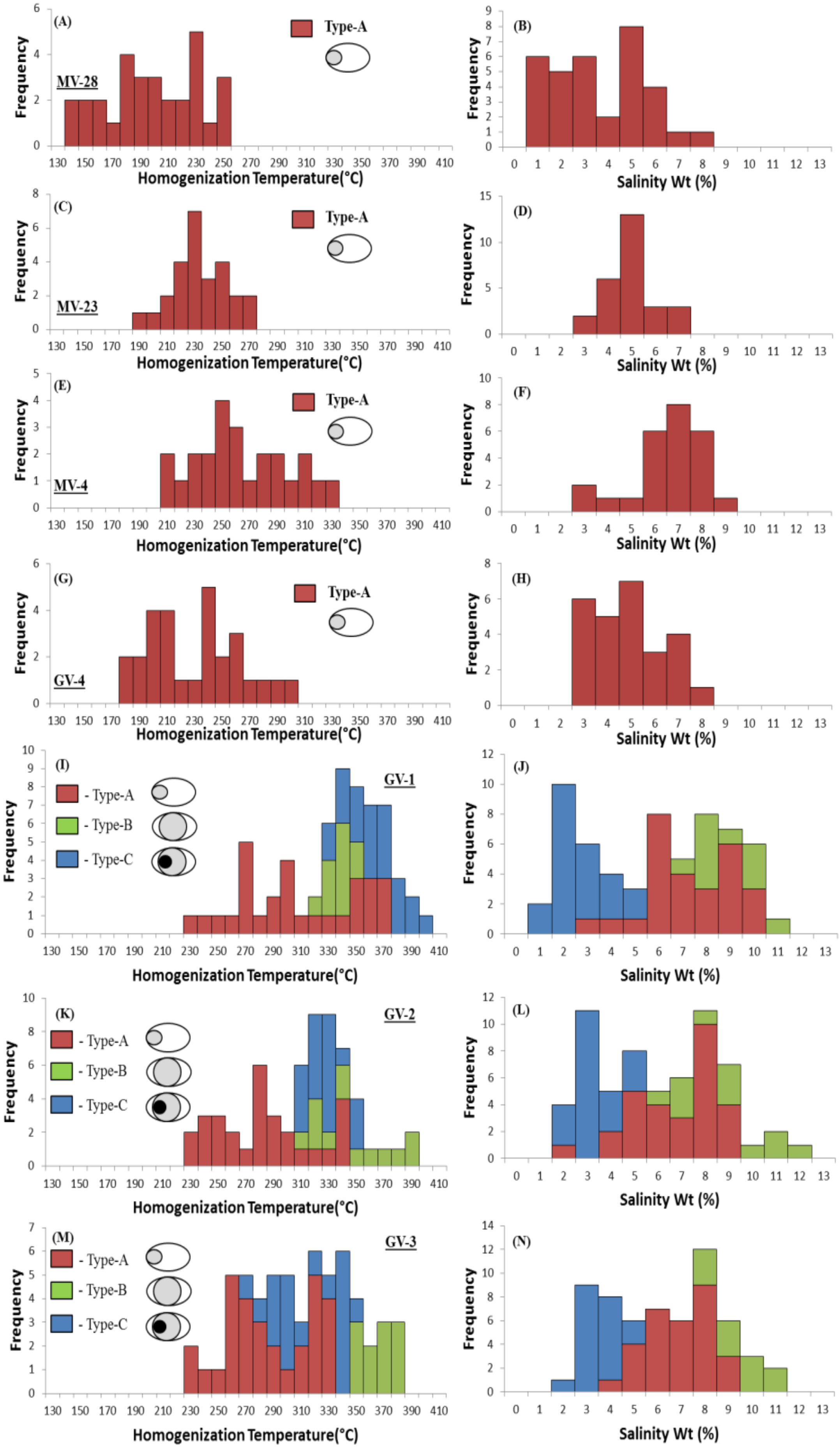


Figure.5. Photomicrographs of fluid inclusion types of the Tagu Sn-W deposit at room temperature.

Table 1. Summary of Fluid Inclusion Types and Microthermometric Data of the Tagu Sn-W Deposit, Southern Myanmar.

Samples	Type	Tm,CO2 (°C)	Tm,clath (°C)	Th,CO2 (°C)	Th (°C)	Tice (°C)	FI (N)	Salinity (wt.% NaCl eqv.)
MV-28	Type-A				140~250	-0.6~-5.2	N=33	1.1~8.1
MV-23	Type-A				190~270	-1.8~-4.5	N=27	3.1~7.2
MV-4	Type-A				210~330	-1.9~-6.1	N=25	3.2~9.3
GV-1	Type-A				230~370	-2.0~-7.1	N=27	3.4~10.6
	Type-B				320~350	-5.0~-7.4	N=11	7.9~11.0
	Type-C	-59.5~-56.8	7.3~9.1	28.1~31.1	330~400		N=22	1.8~5.2
GV-2	Type-A				230~340	-1.7~-6.5	N=30	2.9~9.9
	Type-B				310~390	-4.2~-8.4	N=12	6.7~12.2
	Type-C	-59.1~-57.2	7.1~8.9	27.8~30.8	310~350		N=20	2.2~5.6
GV-3	Type-A				230~330	-2.6~-5.9	N=30	4.3~9.1
	Type-B				350~380	-5.1~-7.5	N=11	8.0~11.1
	Type-C	-58.8~-56.9	7.1~8.6	28.3~30.9	270~350		N=19	2.8~5.6
GV-4	Type-A				180~300	-1.8~-5.3	N=28	3.1~8.3

Tm,CO_2—final melting temperature of CO_2; Tm,cla—final melting temperature of CO_2 clathrate; Th,CO_2—partial homogenization temperature of CO_2 inclusions;Th—total homogenization temperature of inclusions; Tice—final ice melting temperature, FI(N)— fluid inclusion number



(A)
MV-28
Type-A
Frequency
Homogenization Temperature(°C)
(B)
Frequency
Salinity Wt (%)
(C)
MV-23
Type-A
Homogenization Temperature(°C)
(D)
Salinity Wt (%)
(E)
MV-4
Type-A
Homogenization Temperature(°C)
(F)
Salinity Wt (%)
(G)
GV-4
Type-A
Homogenization Temperature(°C)
(H)
Salinity Wt (%)
(I)
GV-1
- Type-A
- Type-B
- Type-C
Homogenization Temperature(°C)
(J)
Salinity Wt (%)
(K)
GV-2
- Type-A
- Type-B
- Type-C
Homogenization Temperature(°C)
(L)
Salinity Wt (%)
(M)
GV-3
- Type-A
- Type-B
- Type-C
Homogenization Temperature(°C)
(N)
Salinity Wt (%)

Figure 6. Histograms of fluid inclusion microthermometric data of the Tagu Sn-W deposit. (A). Homogenization temperature of type-A fluid inclusions in quartz vein in metasedimentary rocks from MV-28 and; (B). Salinity of type-A fluid inclusions in quartz vein in metasedimentary rock from MV-28; (C). Homogenization temperature of type-A fluid inclusions in quartz vein in metasedimentary rock from MV-23; (D). Salinity of type-A fluid inclusions in quartz vein in metasedimentary rock from MV-23; (E). Homogenization temperature of type-A fluid inclusions in quartz vein in metasedimentary rock from MV-4; (F). Salinity of type-A fluid inclusions in quartz vein in metasedimentary rock from MV-4; (G) Homogenization temperature of type-A fluid inclusions in quartz vein in granitic rock from GV-4; (H) Salinity of type-A fluid inclusions in quartz vein in granitic rock from GV-4; (I) Homogenization temperature of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-1; (J) Salinity of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-1; (K) Homogenization temperature of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-2; (L) Salinity of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-2; (M) Homogenization temperature of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-3; (N) Salinity of type-A, type-B and type-C fluid inclusions in quartz vein in granitic rock from GV-3.

5. Discussions

5.1 Mechanism of ore formation

In the Tagu tin-tungsten deposit, the two-phase aqueous inclusion, vapor-rich fluid inclusion as well as three-phases H_2O-CO_2-NaCl inclusions are the main fluid inclusion types observed in the studied samples. CO_2-bearing inclusions coexisting with vapor-rich and liquid-rich inclusions in groups are generally interpreted as an evidence for fluid immiscibility (Roedder, 1984). Khin Zaw (1984) mentioned that tin-tungsten deposits in Myanmar were formed at less than 360°C with formation temperature of 250°C. In comparison, the homogenization temperature of the Tagu tin-tungsten deposit ranges from 140 to 405°C. Furthermore, the fluid inclusion assemblage of the Tagu tin-tungsten deposit is different from those of other well-known world class tin-tungsten deposits in Myanmar such as Mawchi and Hermyingyi (Khin Zaw, 1978; Khin Zaw and Khin Myo Thet, 1983).

Aung Zaw Myint et al. (2018) also indicated that homogenization temperatures range from 175° to 340°C for the Mawchi vein system, in which liquid-rich two-phase (liquid and vapor) primary fluid inclusions are dominant, and H_2O-CO_2 fluid inclusions are absent. Khin Zaw (1984) had shown that majority of inclusions homogenized about 250°C some filling temperatures of vapor-rich inclusions up to 360°C. According to previous research, no H_2O-CO_2 fluid inclusions were found in granite related tin- tungsten deposit in Myanmar except granite related tin-tungsten deposit of the Tagu area. Figure 7 shows typical hyrothermal fluid evolutions of different fluid inclusion types. It is considered that the parent and original hydrothermal fluid at Tagu was probably CO_2- bearing fluid which evolved to two-phase vapor -rich fluid by fluid immiscibility or phase separation of fluids. Temperature and salinities of two-phase liquid-rich fluid decreased by mixing with meteoric water at the later stage.

The ore-forming fluid of the Tagu tin- tungsten deposit most likely underwent fluid immiscibility process during early stage which is characterized by the similar homogenization temperatures and different salinities in a range (Figure 7). The salinities of the vapor-rich inclusions are higher than those of the CO_2-rich inclusions, which may have resulted from CO_2 separation from the fluid as the temperature and pressure decreased. The escape of gases can lead to an increase in the salinity of the residual fluid. Eventually, the later stage ore fluid was produced by mixing of meteoric water circulated through adjacent metasedimentary rocks.

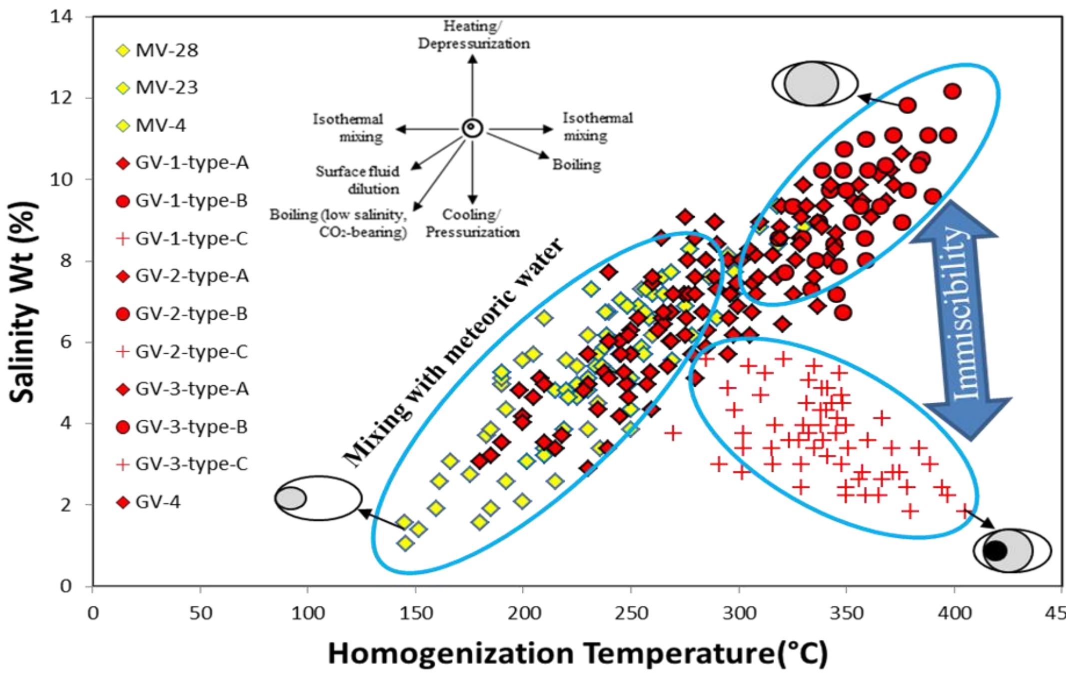


Fig.7. Plot of homogenization temperature (Th) vs. salinity of fluid inclusion data from the Tagu Sn-W deposit with typical trends of fluid evolution patterns of Wilkinson (2001).

6. Conclusions

Mineralogically, three ore formation stages are recognized as; Oxide ore stage (early); Sulfide stage (late); and Supergene stage. The major tin-tungsten ores are composed of cassiterite and wolframite which are associated with sulfide minerals. Early formed minerals are characterized by cassiterite and wolframite, followed by sulfide minerals. Some sulfide minerals fill the fractures of cassiterite and wolframite. This suggests that cassiterites and wolframite were formed earlier than other sulfide minerals.

Three main types of fluid inclusions were distinguished from the mineralized quartz veins hosted by granite and metasedimentary rocks. Quartz in the veins hosted in granite corresponding with earlier stage mineralization contains type-A, type-B and type-C fluid inclusions, whereas those in the veins hosted in metasedimentary rocks corresponding with later stage mineralization contains only type-A fluid inclusions. The original ascending ore fluid was probably CO_2-bearing fluid which evolved into two phase fluid by immiscibility due to pressure drop in the mineralization channels.

The ore-forming fluid of the Tagu tin-tungsten deposit probably underwent a fluid immiscibility process during early stage which is characterized by the similar homogenization temperature and different salinities. They have similar homogenization temperatures and are most likely derived from a magmatic to post-magmatic hydrothermal fluids. The salinities of the vapor-rich fluid are higher than those of the CO_2-rich fluid, which may have resulted from CO_2 separation from the fluid as the temperature and pressure declined. The escape of gases can lead to an increase in the salinity of the residual fluid (e.g., Collins, 1979). Subsequently, ore fluid that was derived from magmatic water was probably mixed with meteoric water in the later stage which has circulated through the adjacent metasedimentary rocks.

The present study strongly suggests that the ore-forming mechanisms of the Tagu tin-tungsten mineralization is characterized by fluid immiscibility during an early stage and fluid mixing with meteoric water in a subsequent stage at lower temperature. Further works are recommended to investigate the timing of intrusions and W-Sn mineralization in the Mergui area.

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