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Geochemical and Petrographic Characteristics of Sn-W bearing Granitic rocks in the Tagu Deposit, Myeik Region, Southern Myanmar: Implications for Regional Tectonic Framework

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Abstract

The Tagu deposit, located in the Myeik District, Tanintharyi Region, southern Myanmar, hosts Sn-W mineralization associated with granitic rocks intruding the Carboniferous metasedimentary rocks of the Mergui Group. This study investigates the geochemical and petrographic characteristics of these granitic rocks to elucidate their petrogenesis and tectonic implications. The granites exhibit S-type and peraluminous characteristics, with geochemical signatures such as enrichment in large-ion lithophile elements (LILEs) like Rb and K, and depletion in high-field-strength elements (HFSEs) such as Nb, P, and Ti. These features suggest a magma derived from the partial melting of metasedimentary rocks in a syn-collisional tectonic setting, likely related to the Himalayan orogeny. Petrographic analysis reveals the granites to be composed of quartz, microcline, plagioclase, biotite, and minor muscovite, with textures ranging from coarsely porphyritic to medium-grained. Geochemical data highlight high levels of differentiation, consistent with the evolution of Sn-rich fluids favorable for tin-tungsten mineralization. These findings enhance the understanding of Sn-W metallogenesis in the Myeik region and provide insights into the regional tectonic framework, contributing to broader knowledge of the Southeast Asian Tin Belt.

Keywords: Sn–W mineralization, Tagu Deposit, Granitic Rocks, Geochemical Characteristics, S-Type Granites

မြန်မာနိုင်ငံတောင်ပိုင်း၊ မြိတ်မြို့နယ်၊ တဂူဒေသအတွင်း ခဲမဖြူ အဖြိုက်နက်သတ္တုစွဲဝင်ပါရှိသည့် နှမ်းဖတ်ကျောက်များ၏ ဘူမိဓာတုဆိုင်ရာ သွင်ပြင်လက္ခဏာများအား လေ့လာခြင်း

ဒေါက်တာကျော်သူထွန်း၊ မန်နေဂျာ
အမှတ်-၂ သတ္တုတွင်းလုပ်ငန်း

စာတမ်းအကျဉ်း

တနင်္သာရီတိုင်းဒေသကြီး၊ မြိတ်ခရိုင်တွင် တည်ရှိသော တဂူခဲမဖြူ အဖြိုက်နက် သတ္တုသိုက် သည် မြိတ်အုပ်စု၏ ကာဗွန်နီဖာရပ်စ်သက်တမ်းရှိသည့် အနည်ကျ အသွင်ပြောင်း ကျောက်များထဲသို့ ထိုးဖောက် ဝင်ရောက်နေသော ဂရန်နိုက်ကျောက်များနှင့် ဆက်စပ်နေသည့် ခဲမဖြူ အဖြိုက်နက် သတ္တုသိုက်ဖြစ်ပါသည်။ ဤလေ့လာမှုတွင်ခဲမဖြူအဖြိုက်နက်စွဲဝင်ပါရှိသည့် ဂရန်နိုက်ကျောက်များ ၏ ဘူမိဓာတုဗေဒနှင့်ကျောက်သားများ၏ လက္ခဏာများကိုလေ့လာကာ ၎င်းတို့၏ ဖြစ်စဉ်နှင့် တက်တိုးနစ်ဆိုင်ရာ အဓိပ္ပာယ်များကို ရှင်းလင်း စေမည်ဖြစ်ပါသည်။ ဤဂရန်နိုက် ကျောက်များသည် S-type နှင့် peraluminous လက္ခဏာများကို ပြသပြီး Rb နှင့် K ကဲ့သို့သော လိုက်အိုင်းယွန်း လစ်ဖိုင်လီအယ်လီမင့်များ (LILEs) ကြွယ်ဝခြင်းနှင့် Nb, P, နှင့် Ti ကဲ့သို့သော မြင့်မားပြီး အားကောင်း သည့် အယ်လီမင့်များ (HFSEs) လျော့နည်းခြင်းကဲ့သို့သော ဘူမိ ဓာတု လက္ခဏာများကိုပြသပါသည်။ ဤအင်္ဂါရပ်များသည် ဟိမဝန္တာ တောင်တန်းဖွဲ့စည်းမှုနှင့် ဆက်စပ် နိုင်သောတိုက်ကြီးများ အတူတကွ တိုက်မိသည့် တက်တိုးနစ်ဆိုင်ရာနေရာများတွင် အနည်ကျ အသွင်းပြောင်း ကျောက်များ၏ တစ်စိတ် တစ်ပိုင်း အရည်ပျော်မှုမှ ဆင်းသက်လာသော ကျောက်ရည်ပူများကို ညွှန်ပြနေပါသည်။ ကျောက်သား ဆိုင်ရာလေ့လာမှုများအရ ဂရန်နိုက် ကျောက်များသည် သလင်း၊ မိုက်ခရိုကလိုင်း၊ ပလေဂျီယိုကလေ့စ်၊ ဘိုင်အိုတိုက်နှင့် အနည်းငယ် သော မာစကိုဗိုက်တို့ဖြင့် ဖွဲ့စည်းထားပြီးရွယ်စေ့များ၏ အသွင်အပြင်မှာ ရွယ်စေ့ကြီးမှ အလယ် အလတ် အနေအထားအထိရှိသည်။ ဘူမိဓာတုဒေတာများအရ ဂရန်နိုက် ကျောက်များမှာ differentiation အဆင့် မြင့်မားခြင်းကို ပြသပြီး ဤအချက်သည် ခဲမဖြူ အဖြိုက်နက် သတ္တု ဖြစ်ထွန်းရန်အတွက် သင့်လျော်သော ခဲမဖြူ ကြွယ်ဝသည့် အရည်များ၏ ဖွံ့ဖြိုးမှုနှင့် ကိုက်ညီ

မှုရှိပါသည်။ ဤတွေ့ရှိချက်များသည် မြိတ်ဒေသတွင် ခဲမဖြူ အဖြိုက်နက်သတ္တုတူးဖော်မှုကို နားလည်မှုတိုးတက်စေပြီး ဒေသတွင်း တက်တိုးနစ်ဆိုင်ရာဖွဲ့စည်းပုံကို ပိုမိုနားလည်စေကာ အရှေ့တောင် အာရှတွင် သတ္တုရုပ်ဝန်းများ ဖြစ်ထွန်းမှုဆိုင်ရာ အသိပညာကို ပိုမို တိုးပွားစေပါသည်။

Geochemical and Petrographic Characteristics of Sn-W bearing Granitic rocks in the Tagu Deposit, Myeik Region, Southern Myanmar: Implications for Regional Tectonic Framework

1. Introduction

The Tagu deposit, located in the Myeik region of southern Myanmar, is renowned for its Sn-W (tin-tungsten) mineralization associated with granitic rocks. These mineralized systems are of significant interest due to their economic importance and their role in understanding the geodynamic evolution of Southeast Asia. Sn-W-bearing granitic systems are typically linked to specialized magmatic processes and are often indicative of tectonic settings where crustal melting and extensive differentiation occur. In Myanmar, such mineralized granites are closely related to the evolution of the Southeast Asian Tin Belt, a prolific metallogenic province extending from the southern Yunnan region of China to the Malay Peninsula.

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). Despite the region's economic importance, detailed studies of the geochemical and petrographic characteristics of these rocks remain limited. The Tagu deposit provides an excellent opportunity to investigate the magmatic processes and tectonic framework that have influenced Sn-W mineralization in southern Myanmar. This study aims to elucidate the petrogenesis, geochemical characteristics, and metallogenic significance of Sn-W-bearing granitic rocks in the Tagu deposit. By integrating petrographic and geochemical analyses, this work also explores the implications of these findings for the broader regional tectonic framework, offering valuable insights into the evolution of this segment of the Southeast Asian Tin Belt.

1.1 Regional Geology

The Myeik region lies within the southern extension of the Southeast Asian Tin Belt, one of the world's most significant metallogenic zones. This belt is characterized by a series of granitoids ranging from the Late Triassic to Cretaceous periods, intruded during the complex tectonic evolution of the Tethyan Ocean and its subsequent closure. The tectonic history of the region is marked by multiple episodes of subduction, collision, and post-collisional magmatism, which have collectively shaped the metallogenic architecture of the area. The Tagu deposit is part of the Myeik granitoid complex, which is dominated by highly fractionated granites associated with Sn-W mineralization. These granitoids are typically peraluminous and exhibit geochemical signatures indicative of crustal anatexis, often linked to the reworking of older continental crust. Regionally, the granitic intrusions are spatially and temporally associated with extensive shear zones, which play a critical role in the emplacement and mineralization processes. Geotectonically, the region is influenced by the interaction between the Indian Plate and the Southeast Asian Plate along the Sagaing Fault and related structures. The granitoids of the Myeik region are believed to have formed during the post-collisional stage of the Himalayan orogeny, driven by slab rollback and subsequent lithospheric extension. These processes not only facilitated the generation of granitic magmas but also provided pathways for mineralizing fluids, resulting in the formation of Sn-W-bearing deposits.

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).

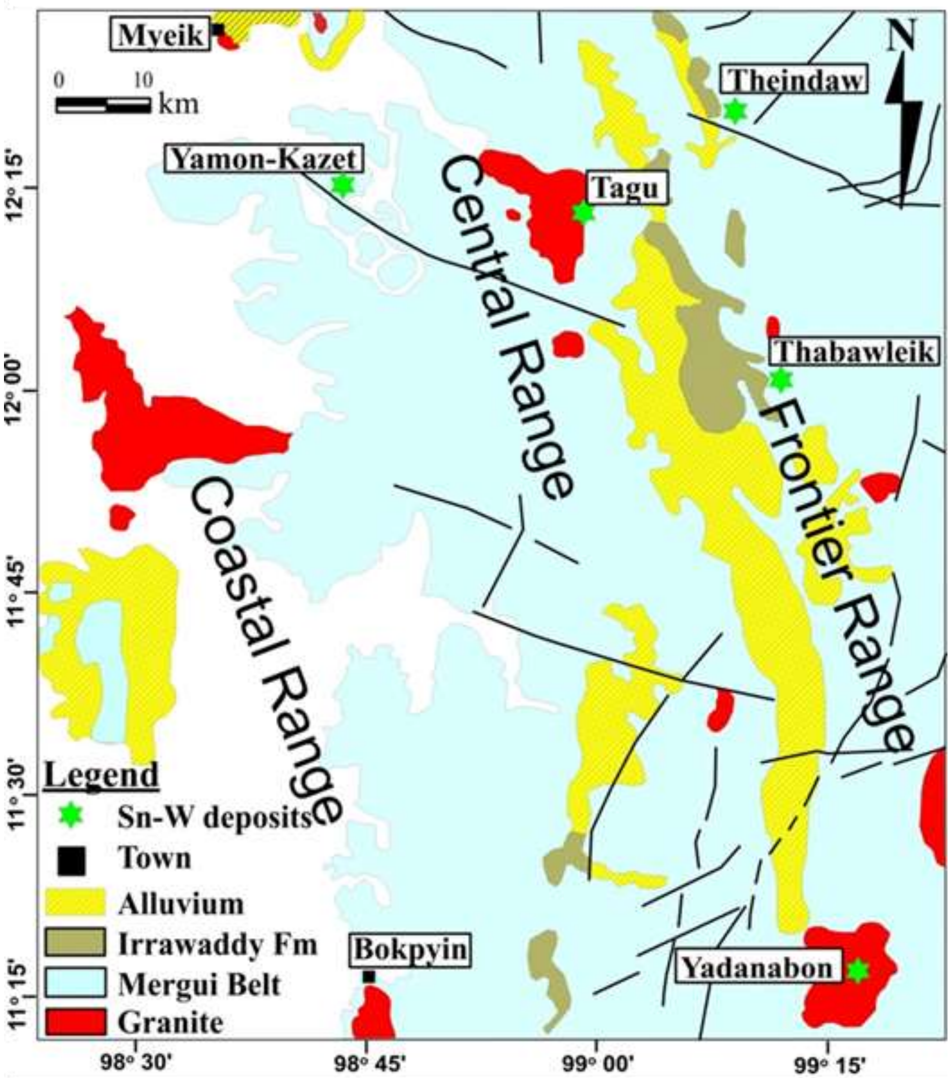

Figure 1. Regional geology of Mergui District (modified from Aung Zaw Myint et al., 2016; Kyaw Thu Htun et al., 2019).

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.

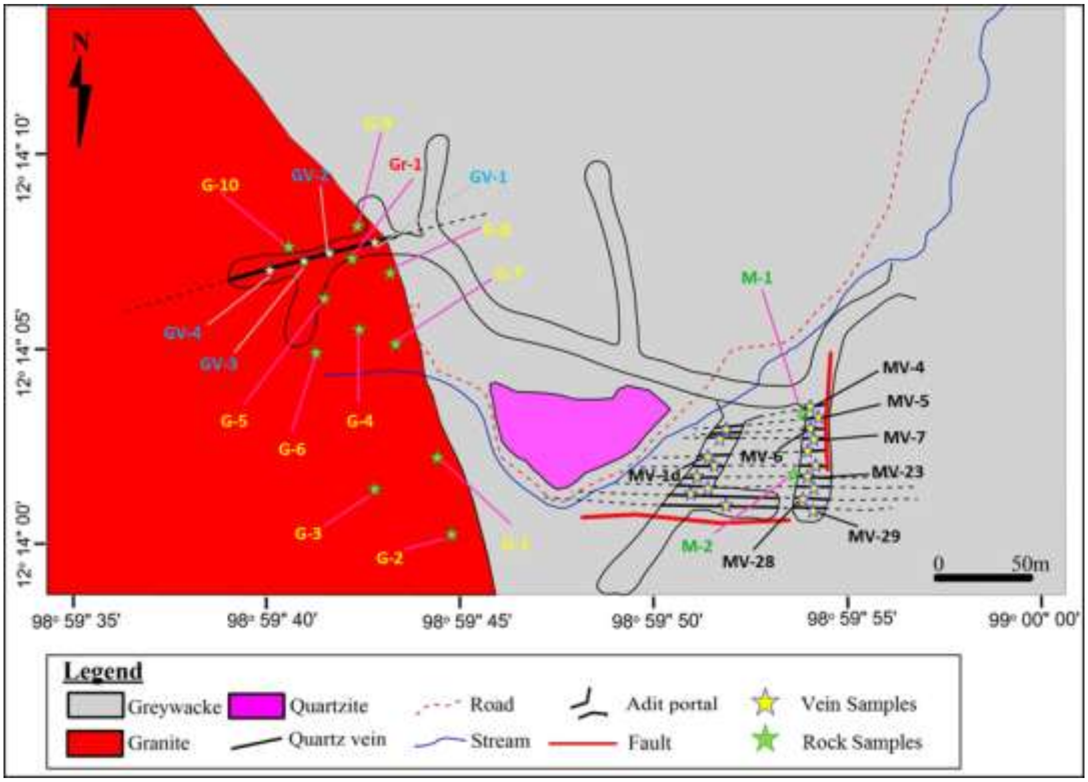

Figure 2. Geological map with sample locations of the Tagu mine area (modified after Tagu mine project map).

2. Objectives

The primary objectives of this research project are as follows:

(a) To improve the geological understanding of the tin-tungsten mineralization in the Tagu area.

(b) To constrain the petrogenesis of granitic rocks and regional tectonic setting using geochemical data.

3. Materials and Methods

A total of 30 samples of granitic rocks from the Tagu area in the Myeik District were collected. Then, 10 representative samples were selected for petrography and whole-rock geochemistry. The concentration of major and minor elements of 10 fresh granitic rocks was determined by X-ray fluorescence Spectroscopy using a RIGAKU RIX-3100 (Rigaku Corporation, Akishima City, Japan) at the Department of Earth Resources Engineering, Kyushu University. Loss on ignition (LOI) was determined by heating the samples at 1000 ◦C for 2 h to determine relative weight loss. The sample pellets for X-ray fluorescence (XRF) analysis were prepared by pressing at 20 t for about 2 min in a vinyl chloride ring. The measurement conditions of analysis were 30 kv and 70 mA and the standard JA-3 andesite (Imai, N et al., 1994) was used to monitor the precision, yielding an error of less than 5%.

4. Results

4.1 Petrography

The petrographic and textural features of the granitic rocks and greywacke are shown in Figure 4. The granitic rocks are coarse-grained, porphyritic, and have microcline, which is associated with quartz, K-feldspar, plagioclase, and biotite (Figure 4A), and secondary muscovite is present as an alteration product of K-feldspar (Figure 4B). The essential constituents are quartz, K-feldspar (orthoclase, microcline), plagioclase, biotite, and opaques (Figure 4B,C). Microcline is predominant over orthoclase.The microcline phenocrysts have inclusions of quartz and twinned plagioclase. The groundmass is composed of quartz, alkali feldspar, plagioclase, and biotite with feldspars partially sericitized (Figure 4D,E). Most of the quartz grains exhibit undulose extinction and plagioclase is highly sericitized. Greywacke of the metasedimentary sequence is fine- to medium-grained. It is mainly composed of quartz, muscovite, and iron oxide minerals. Quartz shows wavy extinction and is anhedral to polycrystalline and poorly sorted (Figure 4F).

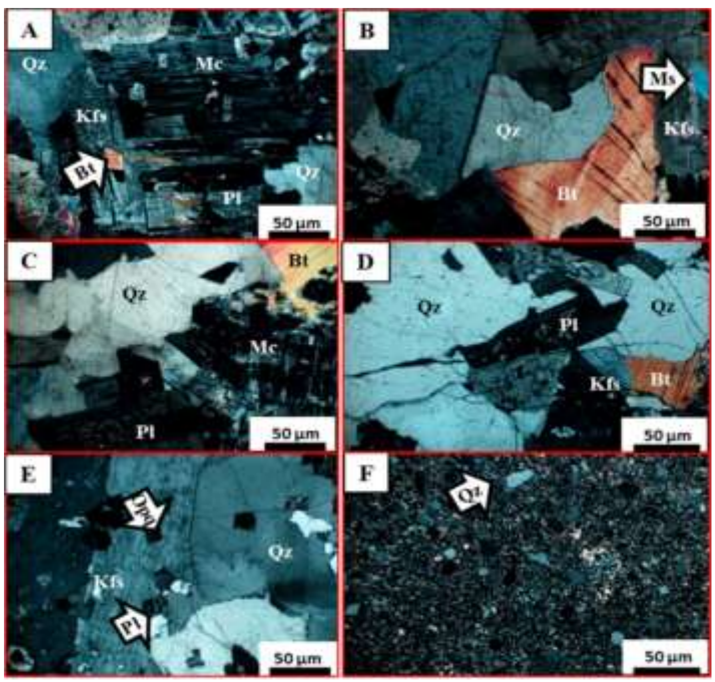

Figure 3. Photomicrographs of granitoids and greywacke at the Tagu tin–tungsten deposit. (A). Microcline associated with plagioclase and K-feldspar with a small amount of biotite ingranite; (B). biotite associated with quartz and K-feldspar with the secondary muscovite in granite; (C). plagioclase associated with microcline and biotite in granite; (D). K-feldspar associated with biotite and plagioclase which is altered to sericite in granite; (E). Quartz occurring with plagioclase and K-feldspar, which has opaque minerals in granite; and (F). greywacke under microscope. Abbreviations: Qz = quartz, Pl = plagioclase, Kfs = K-feldspar, Bt = Biotite, Ms = muscovite, Mc = microcline, Opq = opaque mineral.

4.2 Geochemical Characteristics of Granitic Rocks

4.2.1 Major Oxide Elements

The SiO_2 contents ranged between 69.4 wt.% and 75.9 wt.%, corresponding to a felsic composition. The concentration of Al_2O_3 varied between 12.8 wt.% and 15.8 wt.%. K_2O ranged from 4.4 wt.% to 7.3 wt.%, Na2O (from 1.6 wt.% to 2.5 wt.%), and total alkali content (Na_2O + K_2O) from 6.5 wt.% to 9.6 wt.%. MnO and P_2O_5 concentrations were less than 0.5 wt.%, and LOI values ranged from 0.8 wt.% to 1.7 wt.% (Table 1). These data were applied to construct several discrimination and variation diagrams to distinguish the rocks types, identify their geochemical characters, and constrain the tectonic setting of the granitic magmatism. Harker diagrams (Figure 5) were used for some major oxides relative to SiO_2. Most of the major element oxides, NaO_2, MgO, TiO_2, Al_2O_3, K_2O, and CaO, were negatively correlated with SiO_2 (Figure 5A–F) except the slightly positively correlation with the P_2O_5 contents (Figure 5G). Classification of the rock with SiO_2 versus the K_2O + Na_2O geochemical rock classification diagram of (Middlemost, 1994) for plutonic rocks showed that they plotted in the granite field (Figure 6A). Almost all granite samples from the Tagu area fell in the high-potassium calc-alkaline series in the K_2O versus SiO_2 diagram (Figure 6B) (Peccerillo and Taylor, 1976). The alumina saturation index (ASI) defined by molecular ratio Al_2O_3/(Na_2O + K_2O + CaO) is greater than unity (one) in all the rock samples ranging from 1.17 wt.% to 1.41 wt.%, implying that the granitic rocks were peraluminous S-type (Figure 6C) (Shand, 1943). The alkali-iron-magnesium (AFM) diagram and the relative proportions of the oxides of (Na_2O + K_2O) (A), (FeO + Fe_2O_3) (F), and MgO (M) show a calc-alkaline trend (Figure 6D).

Table 1. Results of major (in wt.%) and trace elements (in ppm) data for theTagu granite samples, Southern Myanmar.

Sample No.	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Major oxide elements (wt%)										
SiO_2	71.53	73.56	71.65	71.79	72.34	71.15	71.15	69.48	71.68	75.98
TiO_2	0.31	0.38	0.32	0.36	0.30	0.27	0.31	0.31	0.36	0.30
Al_2O_3	13.67	13.68	14.95	14.72	14.45	15.06	15.09	15.88	14.36	12.83
FeO	2.08	2.27	2.07	2.08	2.06	1.82	1.88	1.58	2.18	1.68
MnO	0.04	0.04	0.04	0.04	0.03	0.03	0.06	0.02	0.04	0.06
MgO	0.71	0.79	0.77	0.78	0.67	0.61	0.65	0.64	0.72	0.57
CaO	1.23	1.25	1.11	1.00	1.05	1.04	1.16	0.71	1.18	0.61
Na_2O	1.62	2.19	2.28	2.07	2.50	2.39	2.37	2.30	2.24	1.89
K_2O	6.70	4.61	5.01	5.02	4.46	5.92	5.49	7.37	5.59	4.62
P_2O_5	0.16	0.20	0.18	0.17	0.17	0.14	0.15	0.18	0.17	0.15
LOI	1.74	0.86	1.42	1.78	1.51	1.35	1.51	1.30	1.27	1.09
Total	99.79	99.83	99.80	99.81	99.54	99.79	99.81	99.78	99.78	99.77
Trace elements (ppm)										
Sc	1.3	0.8	1.0	2.2	1.7	2.1	2.1	1.8	1.7	1.9
V	31	36	24	25	28	17	25	27	31	21
Co	45	30	40	46	38	30	38	41	29	26
Ni	15	15	11	12	15	13	16	15	14	13
Cu	23	n.d	6	64	34	14	11	3	4	97
Zn	91	12	203	154	81	74	n.d	23	153	61
Pb	44	24	34	65	31	57	52	98	70	109
As	1	9	7	n.d	7	n.d	n.d	n.d	95	148
Mo	12	16	18	15	13	11	11	14	18	15
Rb	911	633	634	621	680	801	846	757	727	835
Sr	32	31	35	36	26	40	46	66	49	25
Ba	349	202	250	264	159	257	318	437	320	234
Y	31	30	29	29	28	33	33	31	31	35
Zr	188	204	197	200	154	158	181	192	210	217
Nb	28	32	27	29	32	27	36	23	29	27
Th	56	61	58	58	47	44	46	49	58	53
U	15	38	44	21	31	19	22	21	13	15
Sb	18	20	14	24	19	18	15	16	21	15
Sn	114	57	50	56	63	53	72	49	59	152
W	36	32	51	60	48	35	349	8	23	35

* n.d = not detected.

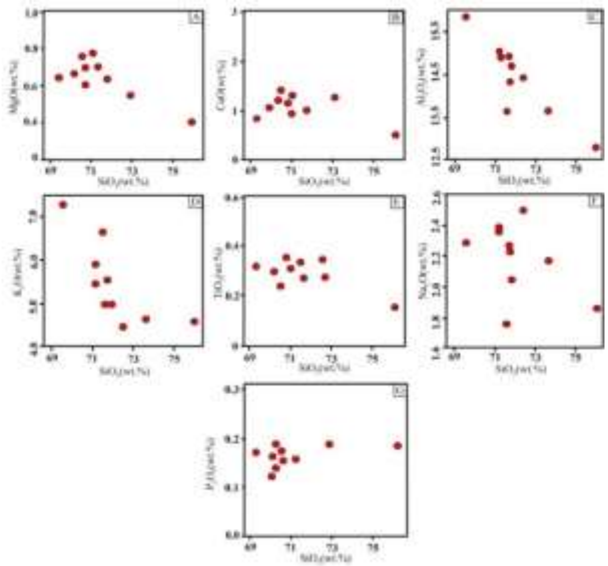

Figure 4. Harker variation diagrams; silica (SiO_2 wt.%) plotted against a range of major oxides (in wt.%) for the granites of the Tagu area. (A). MgO is negatively correlated with SiO_2; (B). CaO is negatively correlated with SiO_2; (C). Al_2O_3 is negatively correlated with SiO_2; (D). K_2O is negatively correlated with SiO_2; (E). TiO_2 is negatively correlated with SiO_2; (F). NaO_2 is negatively correlated with SiO_2; (G). P_2O_5 is slightly positively correlated with SiO_2.

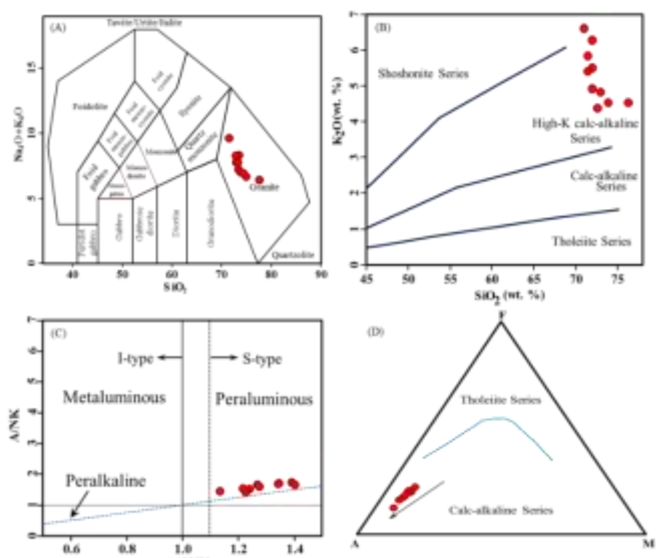

Figure 5. Oxide element geochemical data of granitic rocks from the Tagu area. (A). SiO_2 versus Na_2O + K_2O binary diagram shows that the majority of samples fell in the granitoid field; (B). K_2O wt.% versus SiO_2 wt.%; the subdivisions are by; (C). Alumina saturation index diagram: The A/CNK (molar $Al_2O_3/(CaO + Na_2O + K_2O)$ ratio is greater than *1.1* and it can be assumed that the granite is peraluminous and S-type; (D). AFM triangular diagram for granitoids after. A = (Na_2O + K_2O) wt.%, F = (FeO + Fe_2O_3) wt.%, and M = MgO wt.%.

4.2.2 Trace Elements

Trace element concentrations of the granite rocks from the Tagu are listed in Table 1. The concentrations of large ion lithophile elements, such as Ba (159–437 ppm), Rb (621–911 ppm), Sr (25–49 ppm), and Pb (31–109 ppm), were high. It was noted that the high field strength elements (HFSE), such as Zr (154–217 ppm), Nb (23–36 ppm), Y (28–35 ppm), Th (44–61 ppm), and U (13–44 ppm) were also enriched. The ternary diagram Rb–Ba–Sr was applied to understand the processes for both the classification and genetic types of plutonic rocks (Irvine and Baragar, 1971) (Figure 7A). Trace element discrimination (Y + Nb) versus Rb diagrams (Pearce and Harris, 1984) indicated that the granites of the Tagu area fall in the syn-collisional setting (Figure 7B). A primitive mantle-normalized spider diagram of (Sun and McDonough, 1989) for the granitic rock samples (Figure 7C) reveals the enrichment of large-ion lithophile elements (LILEs), such as Rb, Pb, and K, exhibiting distinct negative anomalies for high-field-strength elements (HFSEs), such as Nb, P, and Ti, and negative anomalies of Ba and Sr from Rb, which are remarkable.

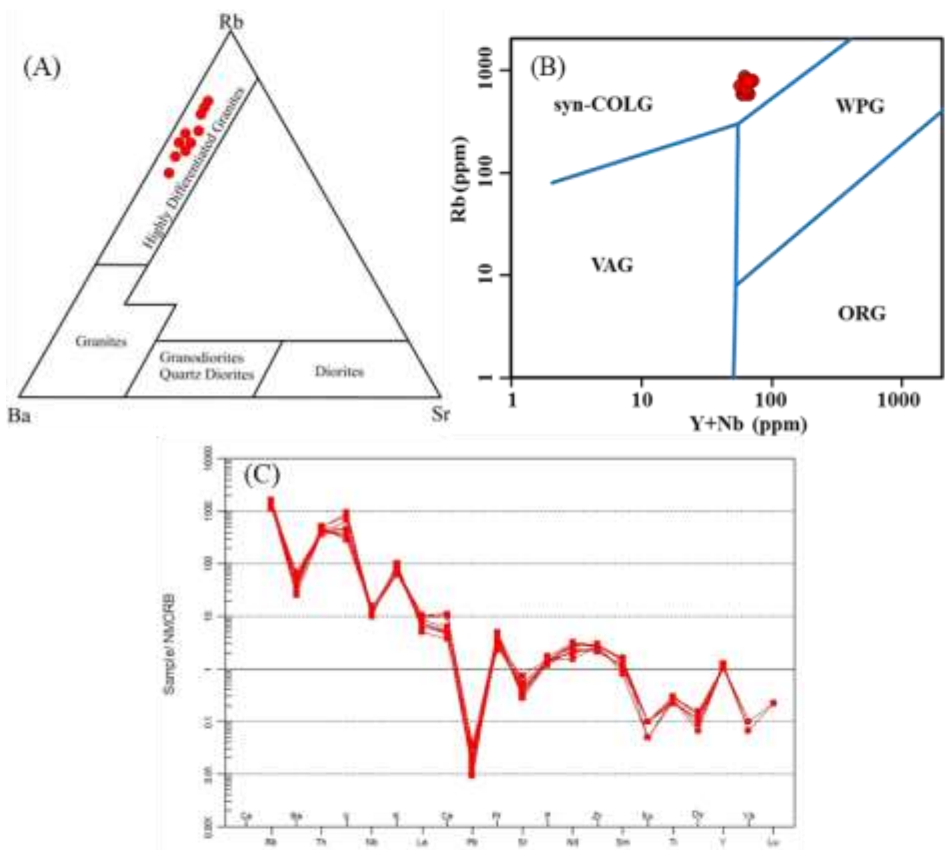

Figure 6. Rb–Sr–Ba triangular diagram. (A). Rb–Sr–Ba triangular plot pointing out the genetic aspect of the Tagu granitoid; (B). Y + Nb versus Rb diagram showing the tectonic setting of the Tagu granitic rocks. (C) Trace element spider diagram. Syn-COLG = syncollisional granites; VAG = volcanic-arc granites; WPG = within-plate granites; ORG = oceanic ridge granites.

5. Discussions

5.1. Petrogenesis of Granitic Rocks

Strongly peraluminous S-type granite formed from the partial melting of peraluminous clastic sediments is common in continental collisional zones, even in Neoarchean time (Yang and Drayson, 2018). The granite of the Tagu tin–tungsten deposit is peraluminous, which is characterized by the A/CNK (molar Al_2O_3/(CaO + Na_2O + K_2O)) value ranging from 1.17 to 1.41. The SiO_2 content is negatively correlated with Na_2O, MgO, TiO_2, Al_2O_3, K_2O, and CaO contents (Figure 5). The content of P_2O_5 in highly fractionated S-type granites was high compared to I-type granites (Chappell and White, 1992; Champion and Bultitude, 2013). In the Tagu tin–tungsten deposit, the P_2O_5 contents of biotite granite were slightly positively correlated with the content of SiO_2. A highly fractionated S-type granitic magma was revealed (Figure 5) and the relationship between Rb–Ba–Sr also exhibited highly fractionated granite (Figure 7A). The granite at Tagu is characterized by generally elevated REE contents with negative Eu anomaly, which can be produced by either partial melting of a plagioclase-rich source or fraction of plagioclase, or a combination of both (Cullers and Graf, 1984). According to the primitive mantle-normalized spider diagram of (Sun and McDonough, 1989), the granite at Tagu (Figure 8B) revealed an enrichment of LILEs, such as Rb, K, and Pb, exhibiting distinct negative anomalies of HFSEs, such as Nb, P, and Ti. Most of these features, such as negative Ba, Sr, Nb, and Ti anomalies and positive Rb, Th, and La anomalies, are compatible to those of typical crustal melt, e.g., S-type granites in North Queensland (Champion and Bultitude, 2013) and the Himalayan leucogranite (Harris and Pearce, 1986). Furthermore, enrichment of Rb, Th, and Y is also consistent with crustal derivation. Thus, parental magma of the granites at Tagu may have been derived from the crustal source.

5.2 Tectonic Setting

The tin granites of WGP have been shown to have been derived from the partial melting of the crust (Gardiner et al., 2016; Myint, A.Z et al., 2017) and the emplacement of these granites has been variously related to the Cretaceous–Paleogene subduction and Himalayan orogeny-related collision (Gardiner et al., 2015), back-arc extension, or post-collisional, syncollisional extension related granitic magmatism (Hobson, 1941; Chen et al., 2015, 2018; Jiang et al., 2017) . Gardiner et al., 2016 considered that tin–tungsten mineralized granites of the Mogok–Mandalay–Mergui (MMM) Belt intruded into the Slate Belt (e.g., at Hermyingyi, Mawchi, and Yadanabon). The zircon U–Pb ages of both mineralized and presumed coeval non-mineralized granites within the MMM Belt are largely of Palaeogene age (Gardiner et al., 2016). The zircon U–Pb ages of 75–50 Ma from granites within the southern MMM Belt suggest that the collision occurred during Late Cretaceous (Gardiner et al., 2016). Mlynarczyk and Williams-Jones, 2005 also noted similar collisional setting from the metallogeny of the Central Andean Tin Belt. (Mitchell et al., 2012) proposed that the Slate Belt represents a separate continental fragment, which was derived from the Gondwana margin and was accreted onto the western Sibumasu margin, probably during the Jurassic period. There is an agreement that by the Early Cretaceous period the subduction of the Mesotethys Ocean beneath the western margin of the Slate Belt–Sibumasu Block was responsible for the growth of a continental-margin plutonic arc. This plutonic arc was described by as the

"Western Granite Province of Southeast Asia" and involved the emplacement of both I- and S-type granites during the Early and Late Cretaceous–Eocene period. S-type granites occur in various settings that are generally related to plate convergence. Perhaps the best constrained are the S-type granites that clearly formed because of the collision of India and Asia (Christiansen and Keith, 1996). Moreover, many S-types are synkinematic. These facts led to the notion that S-type granites are syn-collisiorial granites (Christiansen and Keith, 1996), as in the geochemical classification of (Pearce and Harris, 1984). The granite of the Tagu deposit is highly fractionated and peraluminous and it has the tectonic signature of syn-collisional granites, which confirms that they were emplaced during the collision following the westward subduction of West Myanmar Terrane beneath Sibumasu during the Cretaceous to Tertiary periods.

6. Conclusions

In the Tagu tin–tungsten deposit, nearly E–W trending vertical or steeply dipping mineralized quartz veins are hosted by both Cretaceous to Eocene granite and Carboniferous to Early Permian metasedimentary rocks. The granitic rocks are composed of quartz, feldspars (plagioclase, orthoclase, and microcline), and micas (muscovite and biotite). They are S-type and peraluminous granite, formed in a syn-collisional setting. The granites at Tagu show enrichment of LILEs, such as Rb, and K, and exhibit distinct negative anomalies of HFSEs, such as Nb, P, and Ti, indicating derivation of magma from the lower continental crust. The S-type granites at Tagu were produced through partial melting of the metasedimentary rocks.

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8. References

Audétat, A., Günther, D., Heinrich, C.A., 2000. Magmatic-hydrothermal evolution in a fractionating granite: insights with LA-ICP-MS analysis of fluid inclusions. Science 279, 2091–2094.

Burnham, C.W., 1979. Magmas and hydrothermal fluids. In: Barnes, H.L. (Ed.), Geochemistry of Hydrothermal Ore Deposits. John Wiley and Sons, New York, pp.71–136.

Candela, P.A., 1997. A review of shallow, ore-related granites: textures, volatiles and ore metals. J. Petrol. 38, 1619–1633.

Champion, D.C.; Bultitude, R.J. The geochemical and Sr–Nd isotopic characteristics of Paleozoic fractionated S-types granites of north Queensland: Implications for S-type granite petrogenesis. Lithos 2013, 162–163, 37–56.

Chappell, B.W.; White, A.J.R. I- and S-type granites in the Lachlan Fold Belt. Trans. R. Soc. Edinb. Earth Sci. 1992, 83, 1–26.

Chen, X.C.; Hu, R.Z.; Bi, X.W.; Zhong, H.; Lan, J.B.; Zhao, C.H.; Zhu, J.J. Petrogenesis of metaluminous A-type granitoids in the Tengchong–Lianghe tin belt of southwestern China: Evidence from zircon U–Pb ages and Hf–O isotopes, and whole rock Sr–Nd isotopes. Lithos 2015, 212, 93–110.

Chen, X.C.; Zhao, C.H.; Zhu, J.J.; Wang, X.S.; Cui, T. He, Ar, and S isotopic constraints on the relationship between A-type granites and tin mineralization: A case study of tin deposits in the Tengchong-Lianghe tin belt, southwest China. Ore Geol. Rev. 2018, 92, 416–429.

Christiansen, E.H.; Keith, J.D. Trace element systematics in silicic magmas: A metallogenic perspective. In Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration; Short Coures Notes; Wyman, D.A., Ed.; Geological Association of Canada: St. John’s, NL, Canada, 1996; Volume 12, pp. 115–151.

Cullers, R.L.; Graf, J.L. Rare Earth Elements in Igneous Rocks of the Continental Crust: Intermediate and Silicic Rocks-Ore Petrogenesis. In Rare Earth Element Geochemistry; Henderson, P., Ed.; Elsevier: Amsterdam, The Netherlands, 1984; pp. 275–316.

Gardiner, N.J.; Searle, M.P.; Robb, L.J.; Morley, C.K. Neo-Tethyan magmatism and metallogeny in Myanmar—An Andean analogue? J. Asian Earth Sci. 2015, 106, 197–215.

Gardiner, N.J.; Robb, L.J.; Morley, C.K.; Searle, M.P.; Cawood, P.A.; Whitehouse, M.J.; Kirkland, C.L.; Roberts, N.M.; Myint, T.A. The tectonic and metallogenic framework of Myanmar: A Tethyan mineral system. Ore Geol. Rev. 2016, 79, 26–45.

Harris, N.B.W.; Pearce, J.A.; Tindle, A.G. Geochemical characteristics of collision-zone magmatism. Spec. Publ. Geol. Soc. Lond. 1986, 19, 67–81.

Hobson, G.V. A geological survey in parts of Karenni and the Southern Shan States. Geol. Surv. India Mem.1941, 74, 103–105.

Htun, T., Htay, T.; Zaw, K., 2017. Tin–tungsten deposits of Myanmar. Geol. Soc. Lond. Mem., 48, 625–647.

Imai, N.; Terashima, S.; Itoh, S.; Ando, A. 1994 compilation of analytical data for minor and trace elements in seventeen GSJ geochemical reference samples, “Igneous rock series”. Geostand. Newsl. 1995, 19, 135–213.

Irvine, T.N.J.; Baragar, W.R.A. A guide chemical classification of the common volcanic rock. Can. J. Earth Sci. 1971, 8, 523–548.

Jiang, H.; Li, W.Q.; Jiang, S.Y.; Wang, H.; Wei, X.P. Geochronological, geochemical and Sr Nd-Hf isotopic constraints on the petrogenesis of Late Cretaceous A-type granites from the Sibumasu Block, Southern Myanmar, SE Asia. Lithos 2017, 268, 32–47.

Kyaw Thu Htun; Yonezu, K.; Myint, A.Z.; Tindell, T.; Watanabe, K.,2019. Petrogenesis, Ore Mineralogy, and Fluid Inclusion Studies of the Tagu Sn–W Deposit, Myeik, Southern Myanmar. Minerals, 9, 654.

Marignac, C., Cathelineau, M., 2009. The nature of ore-forming fluids in peri-batholitic Sn-W deposits and a classification. In: Williams (Ed.), Smart Science for Exploration and Mining. Proceedings 10th Biennial SGA Meeting, Townsvillepp. 245–247.

Middlemost, E.A.K. Naming Materials in the Magma/ Igneous Rock System. Earth Sci. Rev. 1994, 37, 215–244.

Mitchell, A.H.G.; Chung, S.L.; Thura, O.; Lin, T.H.; Hung, C.H. Zircon U-Pb ages in Myanmar:

Magmatic–metamorphic events and the closure of a Neo-Tethys ocean? J. Asian Earth Sci. 2012, 56, 1–23.

Mlynarczyk, M.S.; Williams-Jones, A.E. The role of collisional tectonics in the metallogeny of the Central Andean tin belt. Earth Planet. Sci. Lett. 2005, 240, 656–667.

Myint, A.Z.; Suzaki, R.; Yonezu, K.; Watanabe, K.; Ya, K.Z., 2014. Geology of Dawei Sn-W District, Myanmar. In Proceedings of the International Symposium Earth Science and Technology, Fukuoka, Japan, 4–5 December; pp. 244–246.

Myint, A.Z.; Yonezu, K.; Watanabe, K., 2016. Sn-W mineralization in central granitoid belt of Myanmar. In Proceedings of the Oral Presentation at the Annual Meeting of Resource Geology Society, Tokyo, Japan, 22–24 June.

Myint, A.Z.; Zaw, K.; Swe, Y.M.; Yonezu, K.; Cai, Y.; Manaka, T.; Watanabe, K. Geochemistry and geochronology of granites hosting the Mawchi Sn–W deposit, Myanmar: Implications for tectonic setting and granite emplacement. Geol. Soc. Lond. Mem. 2017, 48, 385–400.

Pearce, J.A.; Harris, N.B.W.; Tindle, A.G. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. 1984, 25, 956–983.

Peccerillo, A.; Taylor, S.R. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey. Contrib. Mineral. Petrol. 1976, 58, 63–81.

Pirajno, F., 2009. Hydrothermal Processes and Mineral Systems. Springer, Dordrecht, pp. 1250

Shand, S.J. The Eruptive Rocks, 2nd ed.; John Wiley: New York, NY, USA, 1943; p. 444.

Sun, S.-S.; McDonough, W.F. Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes. Geol. Soc. Lond. Spec. Publ. 1989, 42, 313–345.

Yang, X.M.; Drayson, D.; Polat, A. S-type granites in the western Superior Province: A marker of Archean collision zones. Can. J. Earth Sci. 2018, 1–28.

Zaw, K., 1990. Geological,petrological and geochemical characteristics of granitoid rocks in Burma; with special reference to the associated W-Sn mineralization and their tectonic setting. J. Southeast Asian Earth Sci. 4,293–335.