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MINERALOGICAL AND GEOCHEMICAL CONSTRAINTS ON THE GENESIS OF GRANITE-RELATED W-SN-MO MINERALIZATION IN PADATGYAUNG-MYINMAHTI AREA, EAST OF NAY PYI TAW, CENTRAL MYANMAR*

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Abstract

Padatgyaung-Myinmahti area is located 80km E from Nay Pyi Taw and lies at the eastern margin of the Shan Plateau. W -Sn-Mo mineralization is spatially associated with the biotite granite of Early Eocene age and low-grade metasediments of Carboniferous to Early Permian Mergui Group. The biotite granite is slightly weathered and intensively greisenized in some places. Quartz veins generally trendN-S and NE-SWwith steep dipping (80°-90°). Cassiterite is common in greisenized zone whereas wolframite and molybdenite is prevalent in quartz vein. Greisen is mainly composed of quartz and muscovite with rare fluorite. The quartz veins contain wolframite and molybdenite associated with the minor amount of galena, pyrite, chalcopyrite, sphalerite, arsenopyrite, bismuthinite, cassiterite, scheelite, bornite and covellite. Wolframite composition ranges from hubneritic to ferberitic composition. Geochemical data indicates that the granites are peraluminous and highly fractionated, and characterized by high $SiO_2$and high A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] values(>1.1). The granite has tectonic affinities with WPG (within-plate granite) or post-orogenic setting. Trace element geochemistry, distinct negative anomalies of primitive-mantle normalized Ba, Sr, Ti, Nb and the positive Pb, Rb, Y anomalies reveal that distinct crustal sources have been involved in the formation of granite and associated W-Sn-Mo mineralization.

Keywords: W-Sn-Mo mineralization, mineralogy, geochemistry, petrogenesis

Introduction

Myanmar is located in the Southeast Asian tin belt and has many tin-tungsten deposits and occurrences (Figure 1). Most of the tin-tungsten occurrences are widely distributed in the Padatgyaung-Myinmahti area, Mawchi area, Dawei area and Myeik area. Padatgyaung-Myinmahti area is

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located 72km east from Nay Pyi Taw and forms as a tin-tungsten district comprising several prospects.

Since 1930s, tin-tungsten ore production was initiated in the area of Steel mine (PyiYadanar), Padatgyaung and Peinnedaik. General geology of the area was established by the several workers but detail geological study of granite-related W-Sn-Mo mineralization is poorly understood. Thus, in this research, mineralogical and geochemical studies of granite and associated W-Sn-Mo mineralization is carried out to determine the genesis of granite and associated W-Sn-Mo mineralization.

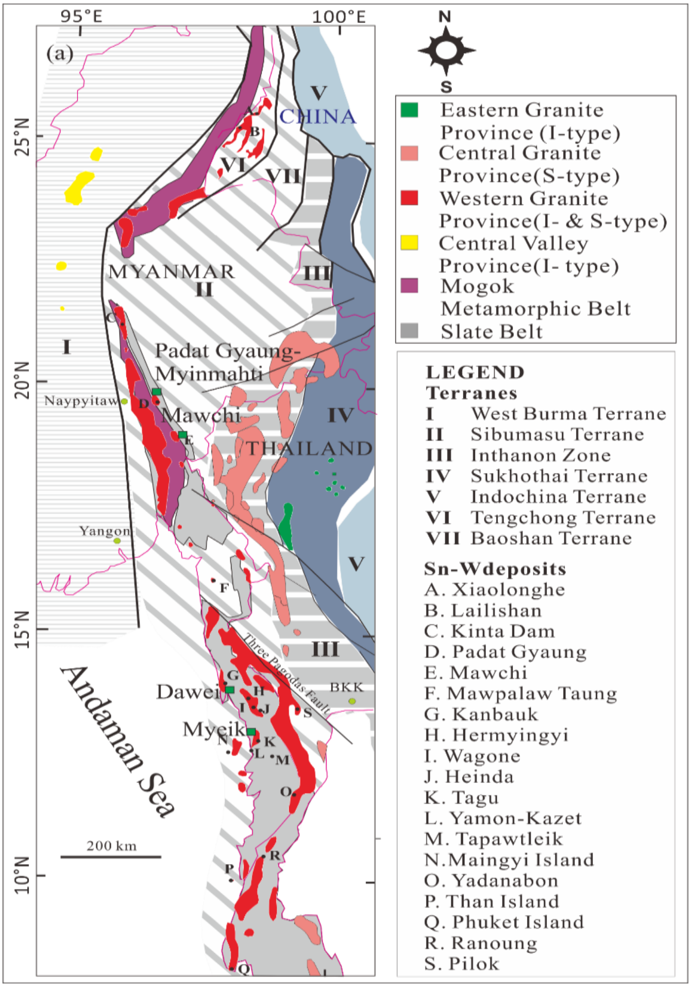

Figure 1: Southeast Asian tin belt showing the occurrences of granite and Sn-W deposits (Aung Zaw Myint et al., 2018 (modified after Cobbing et al., 1992; Mitchell et al., 2007; Sone and Metcalfe, 2008))

Geology of the Padatgyaung-Myinmahti area

Padatgyaung-Myinmahtiarea is composed of the granite and metasedimentary rocks (Figure 2). The metamorphic rocks of the Mogok Metamorphic Belt are exposed in the western part of the area. Banded gneiss and schist are readily observable along the car road to Padatgyaung (Figure 3a). Granite is exposedin the central part of study area, especiallyat the top of and around the Myinmahti Taung (Fig. 3b),formingas north-south elongate pluton. Granite is medium- to coarse-grained, vertically jointed and slightly weathered.The granite is partially greisenized and intruded the Mergui Group (Figure 3c). The greisen is well exposed at Pyiyatanar, Takuntaung and China Cone prospects (Figure 3d).

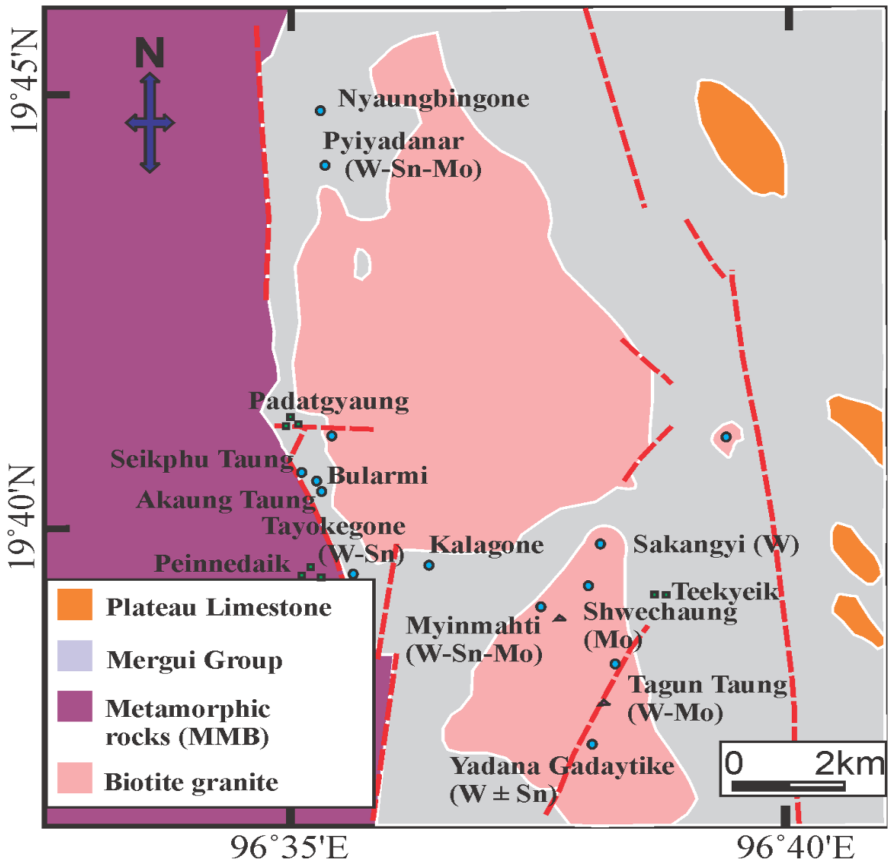

Figure 2: Geological Map of Padatgyaung-Myinmahti area (modified after the sketch map of Bateson et al., 1972)

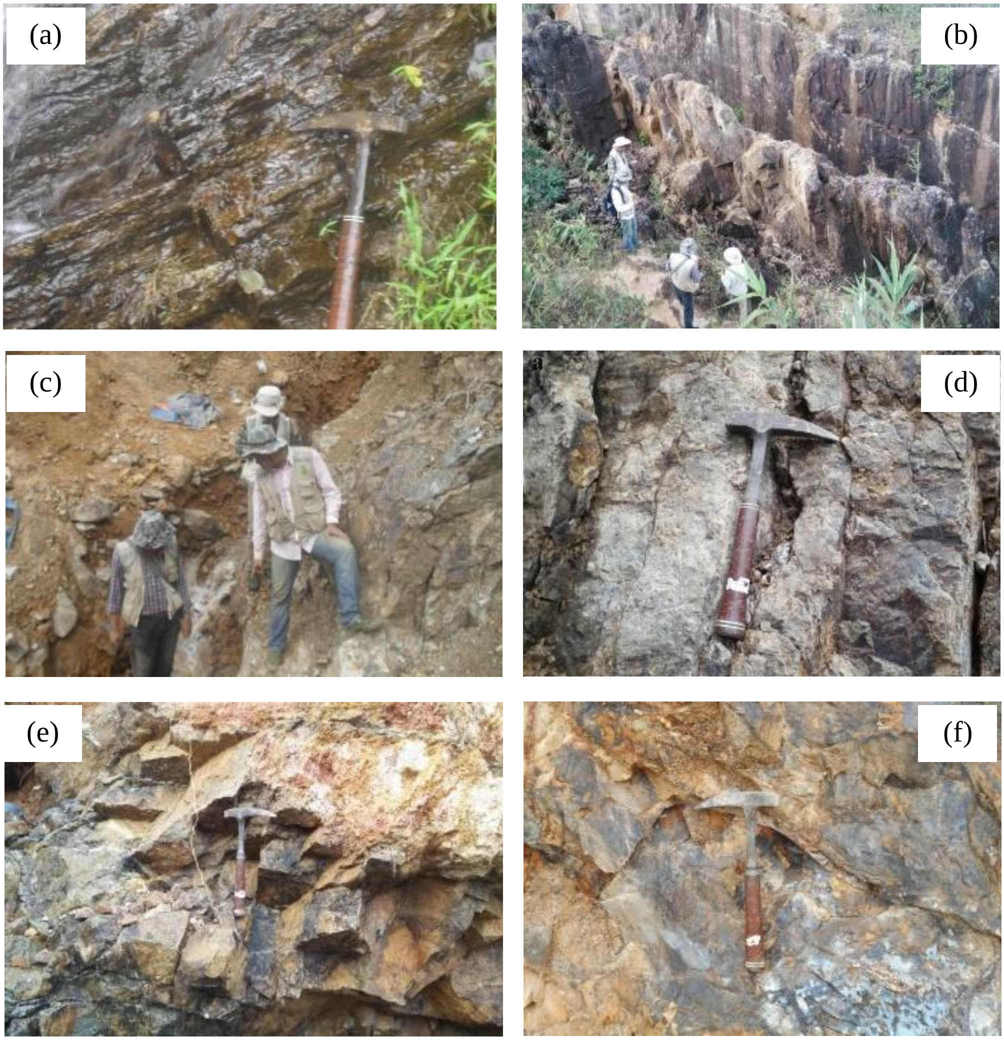

Figure 3: Outcrop nature of rock units exposed in Padatgyaung-Myinmahti area (a) banded gneiss of Mogok Metamorphic Belt (b) weathered granite exposure at the top of Myinmahti hill (c) mudstone intruded by the greisenized granite near Pyiyadanar prospect (d) greisen exposure near Myinmahti (e) well-jointed siltstone unit of Mergui Group (f) metagreywacke unit exposed near Takuntaung Prospect

Metasedimentary and sedimentary rocks distributed in the study areaare sandstone, siltstone, mudstone and metagreywacke. Siltstone with minor thin-bedded sandstone is also found in some localities (Figure 3e). In some localities, the pebbly siltstone has a silicified appearance due to the effect of hydrothermal activity. Metagreywacke is well jointed (Figure 3f) and brecciated. Mudstone is mostly jointed and partly altered. In some places, it contains the quartz pebbles forming as pebbly mudstone.

Granite petrography

Granite is coarse-grained and hypidiomorphic granular texturecomprising quartz, orthoclase, plagioclase, biotite, muscovite and opaque minerals (Figure 4a). Quartz grains are anhedral and formas myrmekite intergrowths with feldspars. Alkali feldspars, orthoclase, microcline and perthite (Figure 4b) occur as subhedral crystals with 0.5 to 2mm size. Plagioclase is generally subhedral to anhedral grains andhas mostly albite composition. Plagioclase is partly altered to sericite and sausurite. Biotiteoccurs as subhedral to anhedral crystals occupying about 10% of the rock. Biotite is partially chloritized (Figure 4c) and exhibits strong pleochroism from yellow to dark brown. Muscoviteoccurs as euhedral to anhedral crystals with size ranging from 0.3mm to 1mm. Iron oxide can be seen as a reddish colored spots.

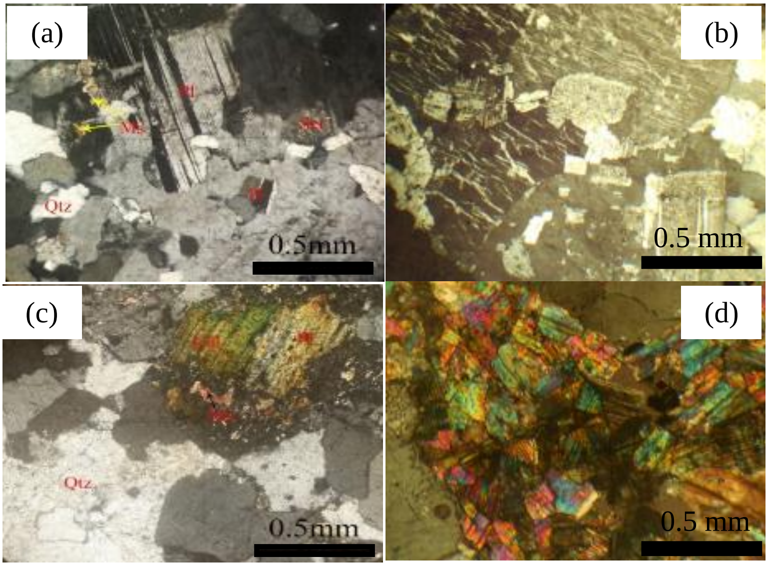

Figure 4: Photomicrographs showing the mineral constituent and textures of granite (a-c) and greisen (d). (a) coarse-grained plagioclase (Pl) with finer grains of quartz (Qtz) and muscovite (Ms), (b)string perthite, (c) partly chloritized (Chl) biotite (Bt) and (d) muscovite aggregate in greisen

Greisenized granite contains chiefly of muscovite, up to 35 percent of the rock, with alkali feldspar and quartz. Greisen is coarse-grainedand mainly composed of muscovite, quartz, (molybdenite) and biotite (Figure 4d). It is greenish grey to dark grey and fragile to compact depending on the portion of mica and quartz. Molybdenite occurs in interstices between muscovite and quartz. Common accessory minerals are cassiterite and fluorite, scheelite and iron oxides are rare accessories. Cassiterite occurs as aggregates of irregular grains and its grain size ranges up to 0.5 cm.

Alteration

The most common alteration associated with W-Sn-Mo mineralization is greisenization. Silicification, sericitization and chloritization are also common. Greisen zone can be served as useful guide for mineral exploration in this area.

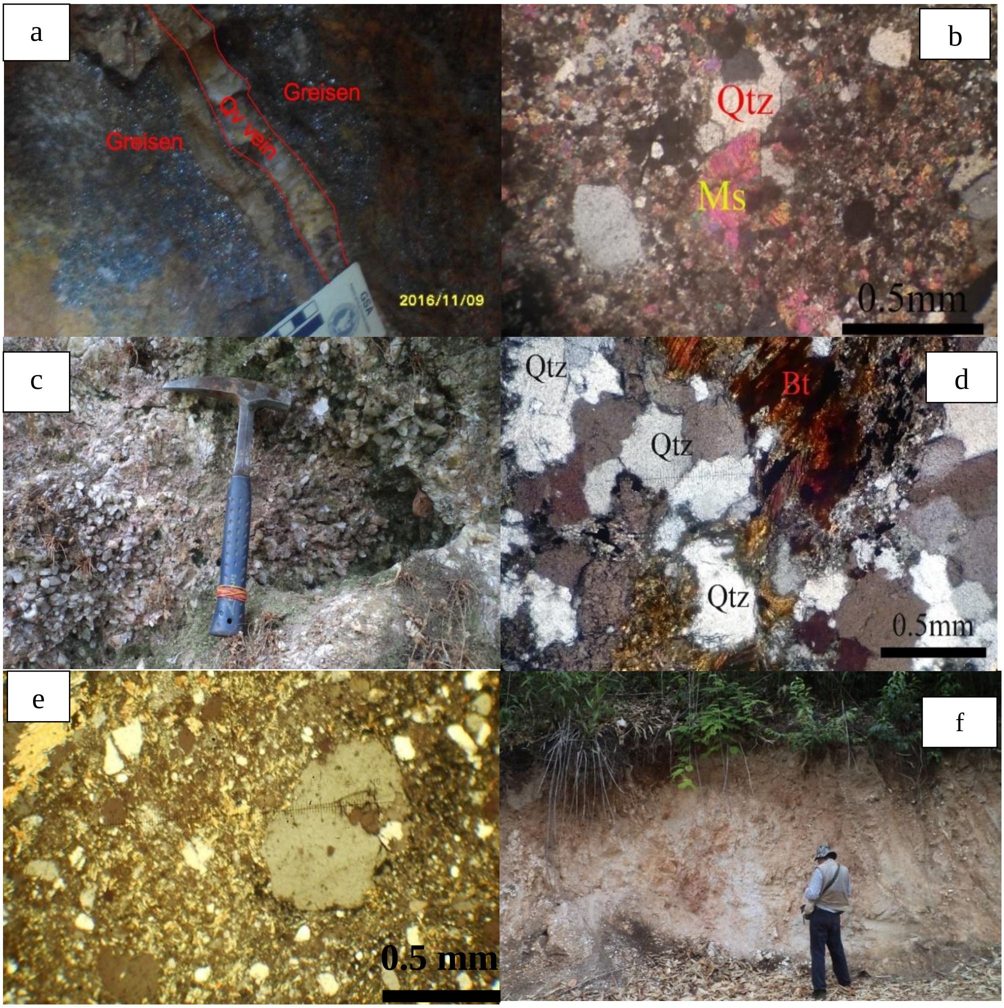

Figure 5: (a) greisenized granite hosting the wolfram bearing quartz vein, (b) greisenization in the siltstone of Mergui Group, (c) silicification occurred in the void of granite, (d) photomicrograph presenting silicification process in granite, (e) sericitization in the metagreywacke and (f) kaolinization on the weathered granite exposed near the top of Myinmahti hill

Greisenization occurs along the margin of mineralized quartz veins, forming as the greisen-bordered quartz veins. Greisen is also found as the form of zonal alteration in the Pyiyadanar, Myinmahti (Figure 5a) and Takuntaung prospects. The greisenization is mainly characterized by quartz and muscovite. In hand specimen,quartz and muscovite are predominant and cassiterite, wolframite and iron oxides are found as common accessory minerals.In Pyiyatanar prospect, greisenization occurs even within the siltstone (Figure 5b). Silicification is the prominent alteration in the mineralized zone. Silicification process can be found at the margin of the granite bodies as vuggy quartz segregation (Figure 5c).Under microscope, the quartz grains are elongate, angular and suture contacts. The small quartz veinlet cut in the granite body (Figure 5d). The quartz grainsoccur as interlocking crystalline mosaic of various shapes. Open spaces such as vesicles, vugs and fractures may also be in filled, often with slightly coarser quartz. Silicification is characterized by the occurrence of vuggy quartz formation.

Under microscopic study, segregate and patches of sericite minerals in metagraywacke indicate the sericitization process (Figure 5e). Apart from the hydrothermal alteration, kaolinization occurs as weathering product of granite (Figure 5f).

Mineralization

The W-Sn-Mo mineralization occurs as both primary and secondary deposits. Primary W-Sn-Mo mineralization can be observed in the Pyiyadanar, Tayokegone, Myinmahti, Shwechaung, Tagon Taung, Sakangyi and Yadana Gadaytike prospects whereas Seikphu Taung, Akaung Taung, Bularmi, Kalagone and Nyaungbingone prospects represent both primary and secondary (i.e.eluvial placer) mineralization. The primary mineralization characterized by the quartz veins that are hosted by the NW-SE, NE-SW and N-S trending fractures, and by greisenized zone. W-Sn bearing quartz veins hosted by metasedimentary rocks are common in the Pyiyadanar (Figure 6a) and other prospects that are located in the western part of the W-Sn-Mo region. The quartz veins closely associated with greisen and cut the sedimentary rocks forming as ore zone. Wolframite and pyrite aggregates, particularly in small voids, are common in these quartz veins. These quartz veins has a thickness of 1cm to 7cm.

Figure 6: (a) parallel quartz vein system intruding the metasediments, (b) biotite granite hosting the quartz vein at Myinmahti, (c) gently inclined vein system at Yadangataytike, (d) greisen-bordered quartz vein at Bularmi, (e) dispersed wolframite (Wf) in quartz vein, and (f) disseminated molybdenite grains (Mo) in greisen

The quartz veins in Myinmahti (Figure 6b) and eastern part of the area are hosted by the greisenized granite. Most of the vein system cut the host rock steeply inclined to vertically. Apart from these vein systems, geisenized granite hosts some subhorizontal to gently inclined veins in Yadanargadaytike (Figure 6c). The greisen-bordered quartz veins are weathered, friable and trend N-S direction forming as a parallel vein system.

In some prospects, the quartz veins are characterized by greisenized border on both sides of the vein (Figure 6d).The mineralization is not related to the vein thickness. All ore minerals occur as irregularly or disseminated in the veins.

The W-Sn minerals can be observed as disseminated grains in quartz vein (Figure 6e). The major ore minerals of wolframite, molybdenite and cassiterite are associated with minor amount of pyrite, chalcopyrite, bornite, galena and fluorite. A quartz vein may be entirely barren in some parts and may be rich in ore minerals in other portions of the same vein.

The greisen zone are mainly found in the Pyiyadanar, Myinmahti, Shwechaungand Takuntaung. Greisen is essentially composed of mica and quartz with minor amounts of cassiterite, wolframite, molybdenite and pyrite. The ores, wolframite and cassiterite, are formed mostly as short and prismatic crystals, lining along the wall of the quartz veins and sometimes as erratically distributed massive patches of several centimeters in the quartz veins. Greisenized zone contains chiefly of molybdenite (± cassiterite ± wolframite) with other sulfides such as pyrite (Figure 6f).

Ore mineralogy

The ore minerals are examined by the polarizing microscope with transmitted and reflected light sources prior to construct paragenetic sequence. All of the ore minerals occur as irregularly patches, disseminated grains, small veinlets and pods in the veins. The ore minerals observed by the ore microscope are wolframite, cassiterite, molybdenite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, bismuthinite and bornite.

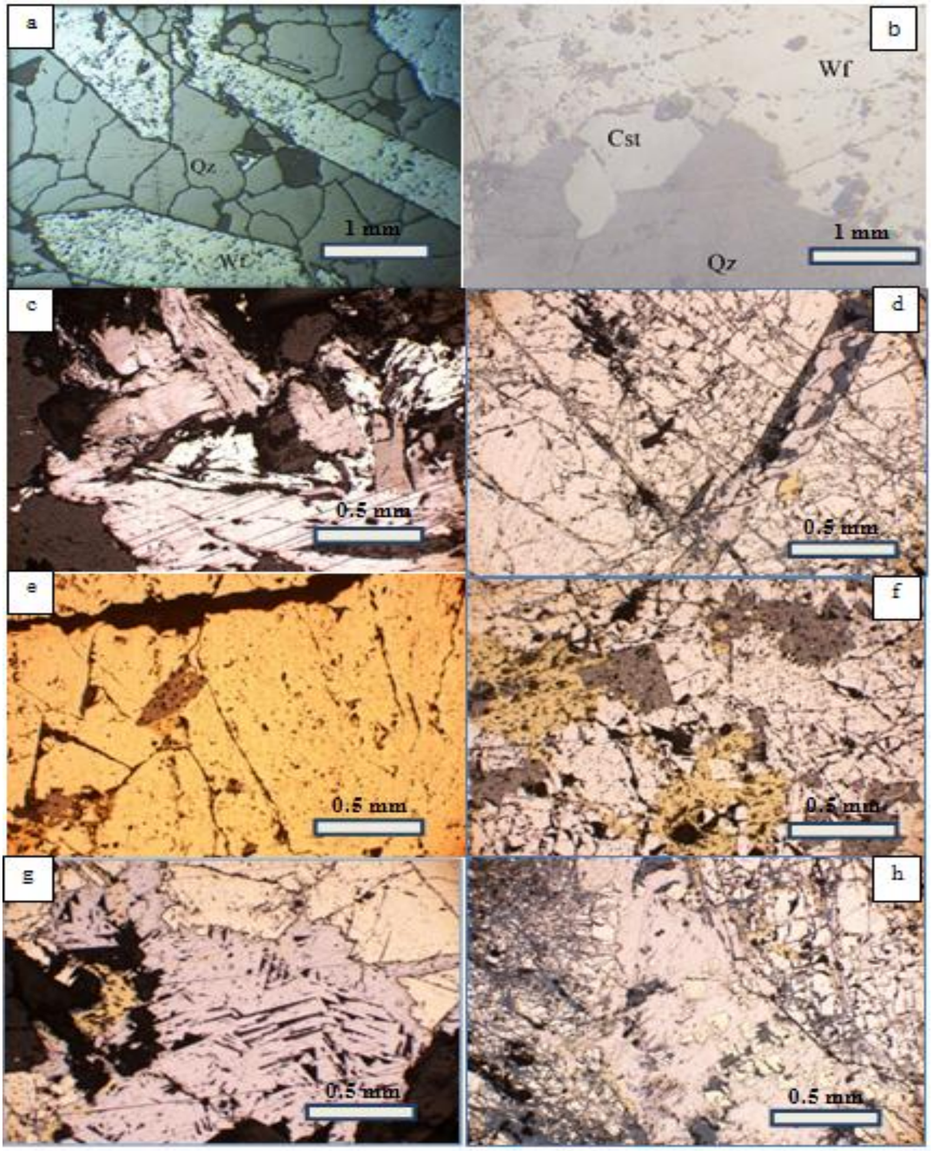

Figure 7: Photomicrographs showing the ore mineral assemblage and their textural relationship: (a) dispersed bladed wolframite crystals in quartz, (b) wolframite and cassiterite in quartz,(c) molybdenite lamellae in quartz (d) fractured arsenopyrite replaced by pyrite and chalcopyrite, (e) voids of pyrite filled with later formed chalcopyrite and sphalerite, (f) chalcopyrite and sphalerite replace pyrite: sphalerite host chalcopyrite blebs (g) triangular-pitted galena replaces early formed pyrite and chalcopyrite, and (h) bismuthinite replaces pyrite cubes and fractured arsenopyrite

Wolframite, the chief ore mineral of the area, occurs as light grey to white, tabular, bladed or prismatic, and lamellar massive (Figure 7a). It is mostly associated with pyrite and molybdenite. Wolframite is usually formed along the walls of greisen-bordered quartz vein. The crystals are more or less perpendicular to the vein walls and projecting into the vein quartz. Individual crystals of wolframite were found up to 0.5 to 1.5 cm long, and sometimes in large masses of crystal aggregate. Wolframite in greisen forms as small crystals and associated with cassiterite.

Cassiterite occurs as common accessory in greisen and its average size is about 1 to 3mm. Cassiterite is associated with wolframite in quartz vein of Myinmahti (Figure 7b). Molybdenite occurs as platy massive aggregate that occurs within or at the margin of quartz veins. It exhibits white to lead grey colour with bluish tint (Figure 7c). Molybdenite is associated with sulfide mineral such as chalcopyrite in quartz vein.

Arsenopyrite is not abundant as pyrite. It is fractured and replaced by the later sulfides such as pyrite and chalcopyrite (Figure 7d). Pyrite is the most common sulfide mineral having yellowish colour, metallic lustre and striated faces on cubes. It is associated with chalcopyrite, galena and sphalerite in quartz veins (Figure 7e) and replaced by these later formed sulfides.

Chalcopyrite has brass yellow and closely associated with sphalerite and pyrite (Figure 7f). It forms later than molybdenite, pyrite and arsenopyrite. It appears somewhat earlier than or synchronously with sphalerite. Sphaleriteis associated with chalcopyrite, pyrite and galena. It is greyish brown to dark grey and has distinct internal reflection. It replaces early formed sulfides such as pyrite and chalcopyrite. Sphalerite encloses chalcopyrite blebs forming as exsolution pattern or chalcopyrite disease texture. Galena is the latest formed mineral in the paragenetic sequence and it is associated with other sulfides such as chalcopyrite and sphalerite (Figure 7g). The bismuthinite, a rare accessory mineral, has whitish colour and replaces early formed sulfides (Figure 7h).

Granite geochemistry

XRF geochemical analysis indicates that the chemical composition of granite samples from the study area contain SiO_2 (74-77%), TiO_2 (0.01-0.3%), Al_2O_3 (10-15%), FeO (0.7-4.2%), MnO (0.16-0.44%), MgO (0.09-0.60%), CaO (0.1-0.53%), Na_2O (0.03-2.19%), K_2O (3.70-6.32%) and P_2O_5 (0.01-0.02%). In fact that SiO_2 content in this rock is extremely high and it can be concluded that it may the mobile nature of SiO_2 and its source is not only from the magma in this case.

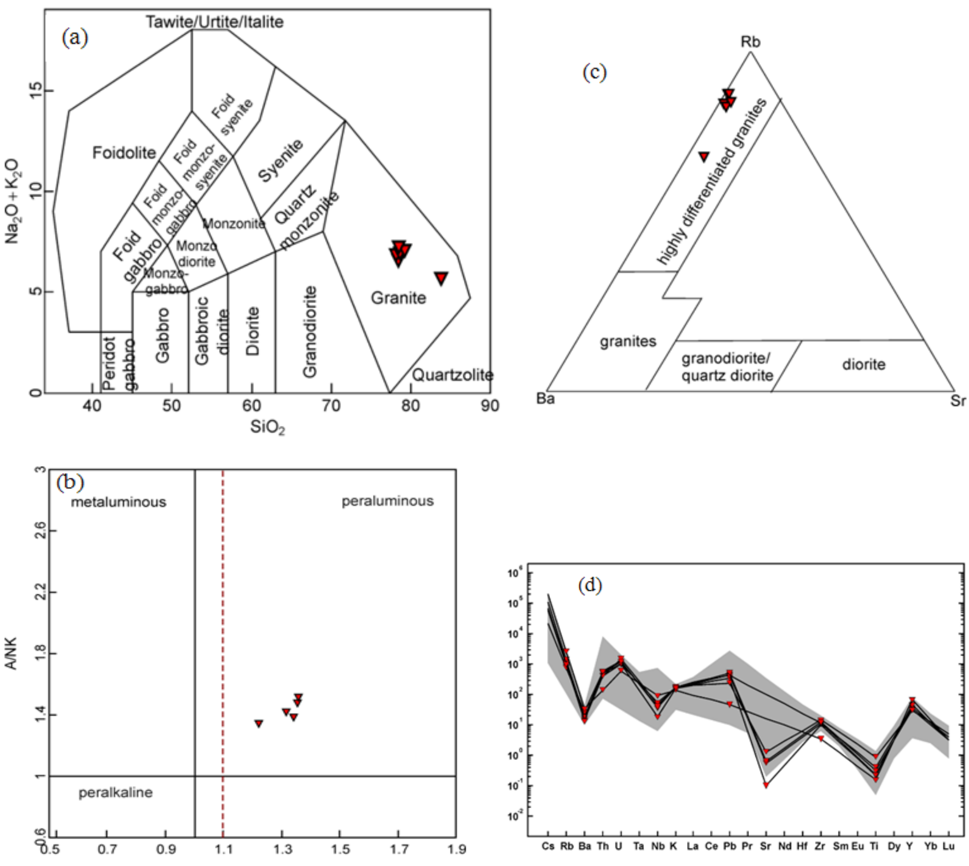

Figure 8: (a) TAS diagram, (b) ASI – A/NK plot showing the peraluminous nature of granites, (c) Rb-Ba-Sr triangular plot presenting highly differentiated (evolved) nature of granites, and (d) spider diagram showing the behavior of trace elements in the granites (red triangle) and greisen (shaded area)

The geochemical data indicates that these granite samples are peraluminous as other tin granites of the Western Province and A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] ≥ 1.1 (Figure 8b). Besides, some of them have the extremely high A/CNK value (i.e.2.7-5.7) and these values cannot be plotted in the diagram of alumina saturation index (ASI) of Shand (1943).

These samples have LILE (large ion lithophile elements) of Rb (450-1780 ppm), Sr (1-30 ppm) and Ba (89-282 ppm). The ternary diagram Rb-Ba-Sr processes the advantage of being both classificatory and genetic (El Bouseily and El Sokkary, 1975). As a genetic factor, the diagram may indicate whether the granites are magmatic or not. Ba and Sr are sensitive indicators for tracing the differentiation trend of the parent magma. In the differentiation sequence from diorites to normal granites Sr decreases while Ba increases. In such case the ratio of K-feldspar to plagioclase mainly governs the differentiation sequence. Sr decreases readily with differentiation since it replaces Ca in plagioclase and K in K-feldspars while Ba replaces only K in K-feldspars. Rb content remains constant from diorite to granodiorite but it begins to increase in normal granite as a result of increase of the amount of K-feldspars. In the differentiation sequence from normal granites to strongly differentiated granites Ba/Rb ratio becomes rapidly variable while Sr content remains virtually constant. Granite samples from Mawchi fall in the division of strongly differentiated granites and the felsic or leucocratic nature of these samples can prove that fact is reliable (Figure 8c).

The granite samples contain HFSE (high field strength elements) of Y (123-334 ppm), Zr (93-202 ppm), Th (18-58 ppm),U (4-24 ppm) and Nb (10-39 ppm).The U content is similar to the values of 3 to 18 ppm usually present in the other granites of Myanmar (Cobbing *et al*., 1992). The samples have poor Zr concentrations expressing the characteristics of low temperature formation and high level emplacement. Granites and greisens from Padatgyaung-Myinnahti area have 19 ppm – 9% Sn, 15 ppm – 0.5% W and 10 – 186 ppm Mo.

Discussion

Petrogenetic consideration

This felsic and highly fractionated magma may be derived from the parent magma, which may be formed by partial melting of the crust, by assimilation and fractional crystalization (AFC process).The distinct crustal sources may have been involved in the peraluminous granitoid rocks. High peraluminosity of the granites also indicate more pelitic sediments may contribute in the magma. However, extended survey for geological mapping and geochemical analysis (eg. ICP-MS determination) and detailed isotopic study are still needed to determine the petrogenes is of granitic rocks.

Nature of parental magma

Mawchi granite is characterized by MORB-normalized spider diagram applying the data analyzed by the XRF method (Figure 8d) showing enrichment in LILEs such as U, Th and Rb, with distinct negative anomalies for HFSEs such as Ti and Nb. Negative anomalies of Ba and Sr from Rb are remarkable. Most of these features such as pronounced negative Ba, Sr, Nb and Ti anomalies and enriched in Rb, Pb andTh are compatible with those of typical crystal melt. Thus the parental magma may be derived from the crustal source.

Tectonic Setting

When plotted on the trace element discrimination diagrams (Pearce et al., 1984; Batchelor and Bowden, 1985), it is clear that the granites from Padatgyaung-Myinmahti area have tectonic affinities with WPG (within-plate granite) and Post-orogenic settings. Pearce et al. (1984) postulated the discriminative diagrams to integrate granite geochemistry into the plate tectonics framework. Among these diagrams Rb-(Y+Nb) diagram is illustrated indemonstrate the link between source and settings. This diagram is based on against function of Rb, essential large ion lithophile and fluid mobile element, to the Y and Nb, two high field-strength and immobile elements. These two HFSEs behave the opposite ways during the process of melting and crystallization. While Nb is almost always incompatible Y may be compatible (Pearce et al., 1984). The granite samples fall in the field of WPG in the discrimination diagrams of Rb-(Y+Nb) (Figure 10a).

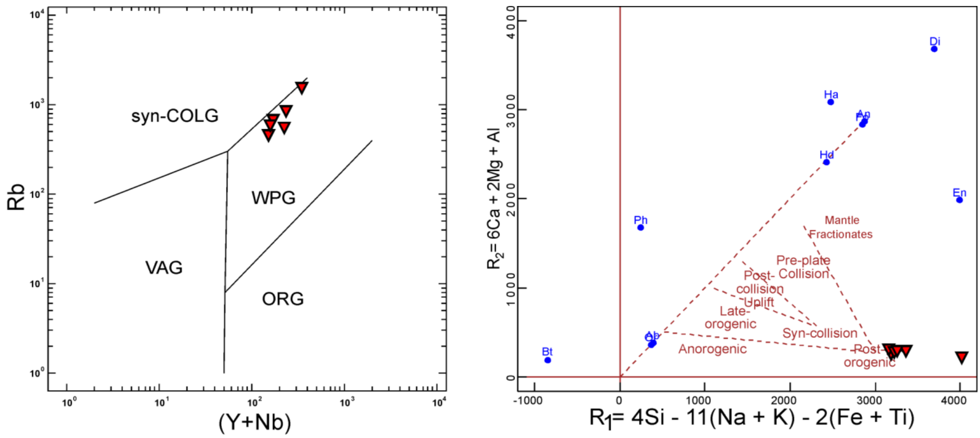

Figure 9: Tectonic affinities of granites from Padatgyaung-Myinmahti area expressed by(a)Rb-(Y+Nb) discrimination diagram (Pearce et al., 1984), and (b)R1-R2 diagram (Batchelor and Bowden, 1985)

Furthermore, the granite samples has tectonic affinities with Post-orogenic granites (Figure 10b) and it can be said that its emplacement is linked with the post-collision movement during the Eocene. The granites exhibit strong depletion of Sr, Ba, Ti and Nb are peraluminous and of S-type. However, more detailed geochemical studies such as ICP-MS analyses and radiogenic isotope (eg. Pb, Nd-Hf, Rb-Sr) are still required to indicate precise tectonic setting and source of granites.

W-Sn-Mo Mineralization

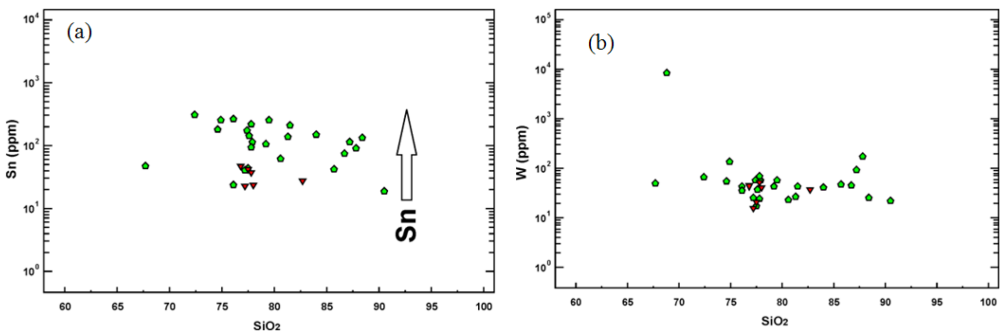

Figure 10: Variation diagram showing the behavior of (a) Sn and (b) W during greisenization process (green pentagon-greisen, red triangle-granite)

The field and lab results reveal that W-Sn-Mo mineralization is genetically related to the granite emplacement. Figure (10) can display obviously the Sn enrichment during greisenization process. However, W abundances in most of greisen samples are not higher distinctly than that in granite samples. It can be concluded that W mineralization is partially related to greisenization but magmatic hydrothermal process is the crucial factor to control the W enrichment in the system.

Conclusions

W -Sn -Mo mineralization is spatially associated with the biotite granite of Early Eocene age and low-grade metasediments of Carboniferous to Early Permian Mergui Group. Quartz veins generally trend N-S, NW-SE and NE-SW with steep dipping (80° -90°). Cassiterite is common in greisenized zone whereas wolframite and molybdenite is prevalent in quartz vein. Geochemical data indicates that the granites are peraluminous and highly fractionated characterized by high SiO_2 and high A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] values (>1.1). Sn enrichment is directly related to the greisenization process whereas magma-decent hydrothermal process controls the W abundances. Trace element geochemistry and tectonic affinities (WPG (within-plate granite) and post-orogenic settings) reveal that distinct crustal sources have been involved in the formation of granite.

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