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GENESIS OF SN-W MINERALIZATION AT MOSAKHEE, MAWCHI SN-W REGION, MYANMAR: CONSTRAINTS FROM MINERALOGY AND GEOCHEMISTRY*

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Abstract

Tin-tungsten mineralization in the Mawchi Sn-W region, Myanmar, is predominantly confined to an Eocene granite and Carboniferous to Early Permian sedimentary and metasedimentary rocks. Apart from the other deposits of the region, stannite-kesterite is the major tin mineral of the Mosakhee, where Sn-W bearing quartz veins cut the metasediments sub-vertically. Stannite-kesterite and wolframite, the major ore minerals of the Mosakhee, are associated with galena, sphalerite, hematite, raspite, cassiterite, and pyrite. The homogenization temperature (*Th*) of vein quartz ranges between 215 and 300 ˚C, corresponding to salinities of less than 10 wt% NaCl equiv. The calculated temperature from the stannite-kesterite and sphalerite pair also coincides with the vein-filling temperatures resulting from fluid inclusion microthermometry. The $\delta^{34}S$ values of stannite (3.6 - 4‰) and galena (4.6 - 6‰) indicate the homogeneous sulfur source. The $\delta^{34}S$ values of galena are heavier than those of the Mawchi deposit, implying a likely different sulfur source derived from the country rocks. A brief account of oxygen isotope reveals that $\delta^{18}O_{H2O}$ calculation of ore fluid at 280 ˚C is 2.9‰ to 4.8‰, suggesting the ore fluid is mainly composed of meteoric water.

Keywords: Sn-W mineralization, Mosakhee, stannite-kesterite, fluid inclusions, stable isotope

Introduction

In Myanmar, tin-tungsten occurrences are spatially associated with the Cretaceous to Eocene granites and metasediments of the Mawchi-Mergui Belt (Gardiner et al., 2016; Aung Zaw Myint et al., 2017, 2018, 2019, 2021; Li et al., 2018a, 2018b, 2019; Mitchell, 2018) (Fig. 1a). Although the common tin minerals in the Southeast Asia tin belt are cassiterite, stannite, and malayaite (Hosking, 1970), the last two tin mineral species are not common in tin-tungsten deposits of Myanmar. Cassiterite is the major tin mineral of Sn-W deposits of Myanmar and is associated with the tungsten minerals of wolframite and scheelite: the latter tungsten species is found only in a few deposits (e.g., Mawchi and Kanbauk). Mawchi Sn-W region is famous for its historic world-class Sn-W deposit, Mawchi, with other prospects such as Khetaung Galay and Hteelakhee (Aung Zaw Myint et al., 2017, 2018) (Fig. 1b). Among the Sn-W occurrences within the Mawchi Sn-W region, Mawchi and Mosakhee are represented by the Sn-W ores with sulfide assemblage, while other prospects have no common sulfide minerals. The steeply dipping Mosakhee quartz veins strike N-S and contain stannite and wolframite as major constituents that are associated with a subordinate amount of sulfides. There is no record of stannite-kesterite occurrence in Myanmar, as the author explained before and, thus, he focuses on the mineralogy, fluid inclusion, and stable isotope to determine the ore genesis of the Mosakhee Sn-W deposit.

Geological background

The Western Granite Province (Cobbing et al., 1986, 1992) of SE Asia contains Jurassic to Miocene I- and S-type granites (Khin Zaw, 1990; Cobbing et al., 1992; Barley et al., 2003; Searle et al., 2007; Mitchell et al., 2012; Gardiner et al., 2016, 2018; Aung Zaw Myint et al., 2017, 2018,

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2021; Crow and Khin Zaw, 2017; Li et al., 2018a, 2018b, 2019) hosted by the metamorphic rocks of the Mogok Metamorphic Belt (MMB; Searle and Haq, 1964; Mitchell et al., 2007) and the sedimentary rocks of the Mergui-Mawchi Belt (Mitchell et al., 2004; Aung Zaw Myint et al., 2021) (Fig. 1a). The MMB occurs as a western margin of the Sibumasu terrane, comprising a metasedimentary and metaigneous sequence of marbles, calc-silicate rocks, schists, quartzites, gneisses, and migmatites (Searle and Haq, 1964; Mitchell et al., 2007; Searle et al., 2007). The Mergui-Mawchi Belt consists of Carboniferous to Early Permian glacio-marine diamictites, including sedimentary rocks and their metasedimentary equivalents defined as Mawchi, Lebyin, Taungnyo, and Mergui Groups in Myanmar, as Kaeng Krachan and Phuket Groups in Thailand, and probably as Kongshuhe Formation in western Yunnan.

The Sn-W mineralization is spatially and genetically related to the Mawchi-Mergui Belt-hosted peraluminous granitic rocks in the Western Granite Province.

Mosakhee prospect is located in the linear metasedimentary rocks of the Mawchi Group (Aung Zaw Myint et al., 2017, 2018), a part of the Mawchi-Mergui Belt, that lay between the high-grade metamorphic rocks of the Mogok Metamorphic Belt (Searle and Haq, 1964: Mitchell et al., 2007) and granitic rocks of Western Granite Province (Cobbing et al., 1992) on the west, and Cambrian to Cretaceous rocks of Shan Plateau on the east (Fig. 1b). Small granite bodies are exposed along the NNW-SSE striking fracture zone, parallel to the regional strike of the Mawchi Group. These granites are mostly biotite granite that is partly altered to tourmaline granite, especially in the Mawchi mine area. The granites are highly evolved, high-K calcalkaline rocks with transitional magmatic-hydrothermal characters (Aung Zaw Myint et al., 2017). Previously reported LA-ICP-MS U-Pb zircon concordia ages of 42.72 ± 0.94 Ma (MSWD = 2) and 43.71 ± 0.39 Ma (MSWD = 1.02) are assigned as magmatic age of biotite granite and tourmaline granite, respectively (Aung Zaw Myint et al., 2017). The prominent rocks of the Mawchi Group are argillites, mudstones, fine-grained sandstone, metagreywacke, slate, and grit. LA-ICP-MS U-Pb geochronological data of detrital zircons from siltstone reveals the depositional age of the Mawchi Group is Carboniferous to Early Permian (Aung Zaw Myint et al., 2017).

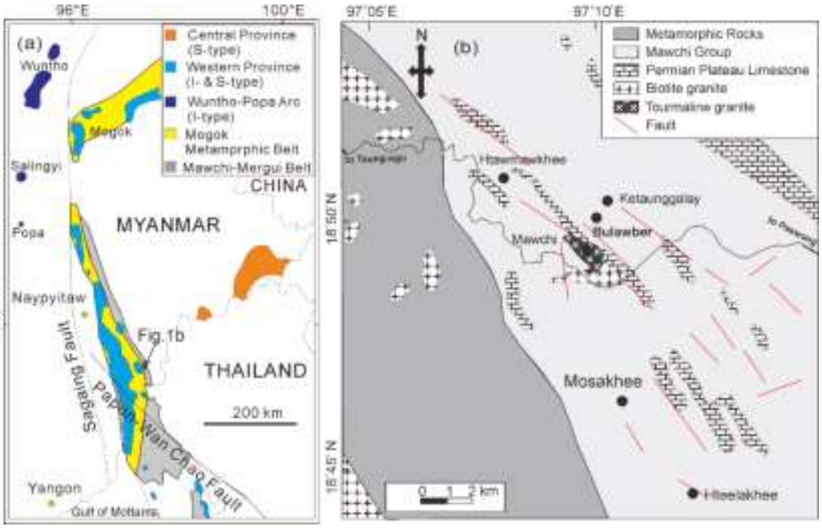

Figure 1: (a) Simplified geological map of Myanmar showing the granitoid belts together with Mogok Metamorphic Belt and Mawchi-Mergui Belt (Aung Zaw Myint, 2015; modified after Cobbing et al., 1992; Mitchell et al., 2007; DGSE, 2008), (b) Geological map of the Mawchi Sn-W district (Aung Zaw Myint et al., 2017, 2018; modified after Mawchi mine project map).

The principal mineralization in Mawchi is represented by N-S striking quartz veins that are confined to the tourmaline granite and metasedimentary rocks. Cassiterite, wolframite, scheelite, pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, cosalite, quartz, tourmaline, fluorite, danalite, micas, and clay minerals occur as major constituents of the vein. Mawchi Sn-W mineralization is confined to both tourmaline granite and metasediments whereas other deposits are mostly hosted by metasediments. A molybdenite Re-Os model age of 42.4 ± 1.2 Ma indicates that the Sn-W mineralization at Mawchi coevals with the timing of granite emplacement (Aung Zaw Myint et al., 2018). Moreover, $^{40}Ar/^{39}Ar$ hydrothermal muscovite plateau ages of (40.14 ± 0.14 Ma; MSWD = 1.48) and (40.80 ± 0.12 Ma; MSWD = 0.47) define the timing of hydrothermal alteration and simultaneous veining that accompanied the late stage of ore-forming at Mawchi (Aung Zaw Myint et al., 2018). The Htawmawkhee prospect is composed of parallel and inclined small quartz veins that strike NW-SE. These 2–14 cm thick veins are hosted by argillite and comprise cassiterite, wolframite, and tourmaline. Nearly N-S trending sheeted veins are also exposed at Htawmawkhee. In the Ketaunggalay prospect, wolframite-bearing quartz and pegmatite veins are hosted by the metasandstone of the Mergui Group and they strike nearly N-S. Hteelakhee, located 12 km south of the Mawchi, represents a tabular and sheeted vein system containing cassiterite and wolframite confined to the argillite and sandstone.

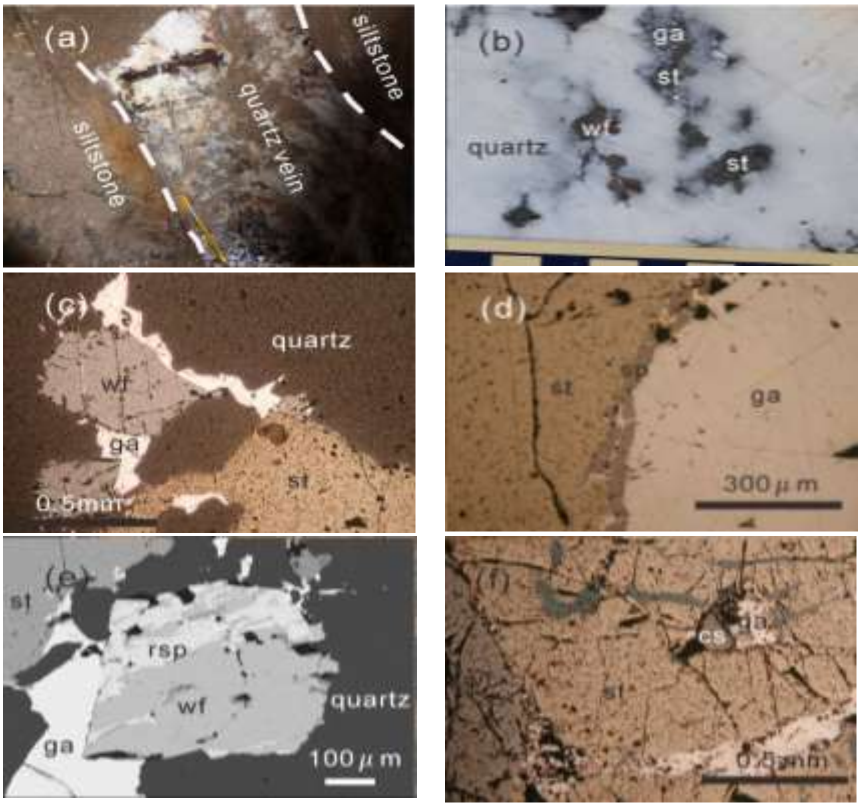

Figure 2: Outcrops (a-b), reflected light photomicrographs (c-d, f), and BSE image (e) displaying the mineralization style and ore mineral assemblages of Mosakhee: (a) sub-vertical quartz vein hosted by siltstone, (b) sulfide and oxide mineral association in the vein quartz, (c) wolframite and stannite marginally replaced by galena, (d) galena and sphalerite replace along the margin of stannite, (e) raspite replacing along the cleavages of wolframite grain, and (f) small cassiterite grain locating in the microfractures of stannite (cs: cassiterite, ga: galena, rsp: raspite, sp: sphalerite, st: stannite, wf: wolframite).

The Mosakhee Sn-W mineralization occurs in the southern part of the Mawchi Sn-W region. At Mosakhee, fine-grained sandstone hosts tabular quartz veins in which wolframite, stannite, and galena are major constituents (Figs. 2a, b). The N-S trending quartz vein comprises individual patches of oxide and sulfide minerals.

Analytical methods

Elemental analyses were performed by a Shimadzu Superscan SSX-550 scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) and a JEOL JXA8530F field emission electron probe microanalyzer at Kyushu University. A calibrated Linkam-THMS600 heating-freezing stage housed in the Economic Geology Lab, Kyushu University, is used for the final ice melting point (salinity calculations) and homogenization temperature measurement of the fluid inclusion samples. Sulfur and oxygen isotopic analysis was conducted at the Scottish Environmental Research Centre (SUERC), Scotland, United Kingdom, and the analytical procedure is explained in Aung Zaw Myint et al., 2018.

Results

Mineralogy and Elemental Determination

The most common vein minerals are stannite-kesterite, wolframite, sphalerite, chalcopyrite, galena, hematite, raspite, and pyrite. Wolframite, the most common tungsten mineral of the deposit, appears as euhedral to subhedral crystals and is veined and marginally replaced by galena (Fig. 2c) and other sulfides. Its composition is generally hubneritic and contains FeO (3.19 to 3.55 wt%) and MnO (20.91 to 21.24 wt%). Stannite-kesterite is the common tin mineral of the deposit, and it contains a range of Fe (4.47 to 7.49 wt%) and Zn (5.53 to 9.21 wt%), showing a small variation of composition. It is spatially associated with galena and fills in the voids of wolframite.

Apart from Mawchi sphalerite, Mosakhee sphalerite rarely hosts chalcopyrite and stannite blebs. Sphalerite contains 1 to 2.38 wt% Fe and 1.41 to 1.97 wt% Cd; it is relatively lower than those of Mawchi sphalerite (2.4 to 11.6 wt% Fe and 2.89 to 3.58 wt% Cd, respectively; Aung Zaw Myint, 2015). Sphalerite replaces the margin of stannite and wolframite, and occurs as the void fills in the stannite (Fig. 2d). Minute pyrite grains can be found as inclusions in stannite. Chalcopyrite occurs as a minor sulfide that represents small crystals associated with sphalerite and galena and replaces stannite. Galena, likely the last forming sulfide mineral in the vein system following sphalerite and chalcopyrite, is the most common sulfide mineral after stannite and sphalerite. Galena veins and replaces along the fractures and margins of wolframite and stannite (Fig. 2c). Raspite (PbWO4), containing 49.28−51.35 wt% WO_3 and 47.88−48.71 wt% PbO, replaces along with the fractures (cleavages) and grain boundaries of wolframite (Fig. 2e). Cassiterite, the most common tin mineral in other deposits within the Mawchi Sn-W district, occurs as small crystals associated with pyrite, galena, and stannite in Mosakhee (Fig. 2f). Hematite occurs as the secondary product of pyrite, containing the relict of the latter.

Fluid Inclusion Studies

Vein quartz from the Mosakhee prospect hosts liquid-rich two-phase fluid inclusions (Fig. 3a) with forty-one fluid inclusions heated to determine the homogenization temperature (*Th*). The fluid inclusions show a size variation from 5 to 25 µm characterized by irregular to tubular shape. The *Th* ranges from 231 to 300 ˚C with a mode of 280 ˚C. Final melting temperatures (*Tm*) range from -1 to -5 ˚C and calculated salinity is less than 10 wt% NaCl equiv. The highest salinity samples correspond to the samples of low homogenization temperature (Fig. 3b).

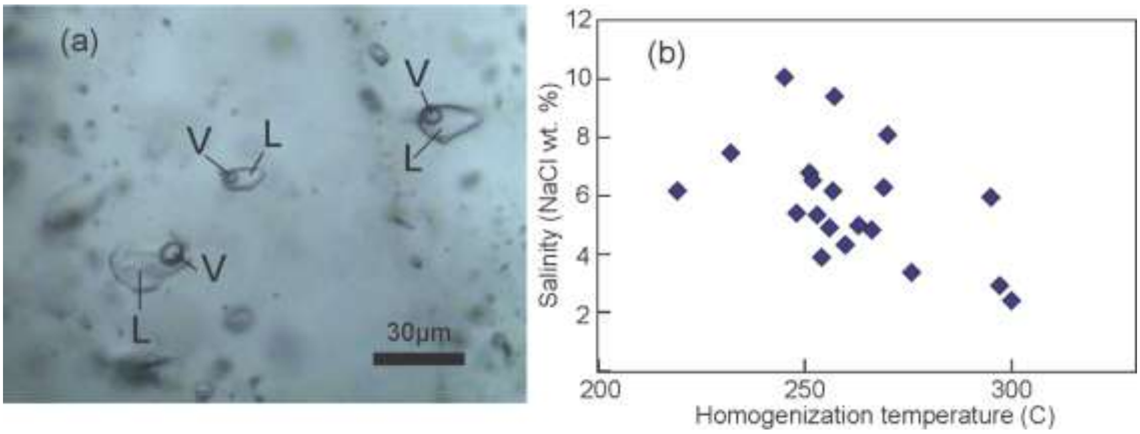

Figure 3: (a) Photomicrograph of liquid-rich two-phase fluid inclusions in the vein quartz of Mosakhee, (b) demonstrating the negative correlation between homogenization temperature and salinity

Stable Isotope

Stannite and galena from the Mosakhee Sn-W prospect gave $\delta^{34}S$ of 3.6-4‰ in stannite and 4.5-6‰ in galena, revealing the homogeneous sulfur source (Fig. 4a). Oxygen isotopes in the wolframite and quartz were analyzed to determine the source of ore fluid, and the $\delta^{18}O_{H2O}$ calculation of ore fluid is based on the mean homogenization temperature of quartz (i.e., 280 ˚C). The $\delta^{18}O_{mineral}$ values of wolframite and quartz were 1.4‰ and 13.2 to 13.3‰, indicating the $\delta^{18}O_{H2O}$ values of 2.9‰ and 4.7 to 4.8‰, respectively (Fig. 4b).

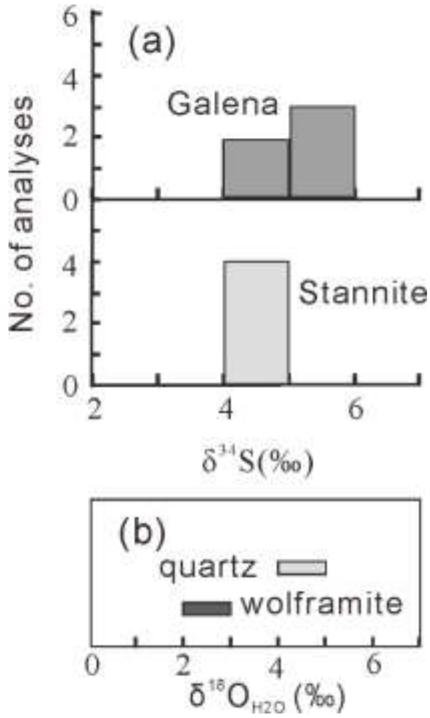

Figure 4: (a) Sulfur isotope values of sulfide minerals and (b) calculated $\delta^{18}O_{H2O}$ values of ore fluid from the Mosakhee

Discussion

Nature of Ore Fluid

Fluid inclusions microthermometric data reveals that the minimum vein filling temperature at Mosakhee is ~ 280 ˚C. It is coherent with the stannite-sphalerite thermometric data that indicates ca. 275 ˚C (Fig. 5). The negative correlation between the *Th* and salinity of the fluid inclusions also suggests a mixing of moderate temperature and low salinity magmatic descent fluid with a cooler and more saline meteoric water percolated in the sedimentary sequence of the Mawchi Group. In addition, the $\delta^{18}O$ values of quartz samples from various veins range from 11.5 to 13.4‰ and they are quite similar to those of Mawchi (11.8 to 13.4‰), Khetaungkalay (13.4‰), and Htawmawkhee (12.9‰) (Aung Zaw Myint, 2015; Aung Zaw Myint et al., 2018). Calculated $\delta^{18}O_{H_2O}$ values of Mosakhee vein quartz range from 3 to 4.9‰, indicating the deficiency of magmatic water component (Taylor, 1974, 1979). Thus, it can be suggested that the magmatic descent water may be involved in the source of ore fluid, but meteoric water is the principal component of ore fluid.

Source of Sulfur

The general mean of $\delta^{34}S$ data (4.6 ± 0.8‰; 1σ, n = 9) is heavier than that of the Mawchi deposit (2.9 ± 2.9‰; Aung Zaw Myint et al., 2018), indicating a relative enrichment in the ^{34}S content of the sulfur source. The $\delta^{34}S$ values of galena (4.5 to 6‰) from Mosakhee are significantly heavier than those of Mawchi (-1.3 to 1.8‰). The source of sulfur for the Mawchi deposit was mainly derived from the granitic magma (Aung Zaw Myint et al., 2018), but the heavier sulfur in Mosakhee was probably derived from country rocks. In addition, relatively lower Cd content in Mosakhee sphalerite than that of Mawchi sphalerite indicates that the metal source from crustal derived magmatic source diminished in the ore deposition at Mosakhee. The ancient crust that produced the magma for Mawchi granite is likely enriched in cadmium that has a similar ionic radius with zinc and can readily be deposited in the places of Zn in sphalerite isomorphically (e.g., Ye et al., 2012).

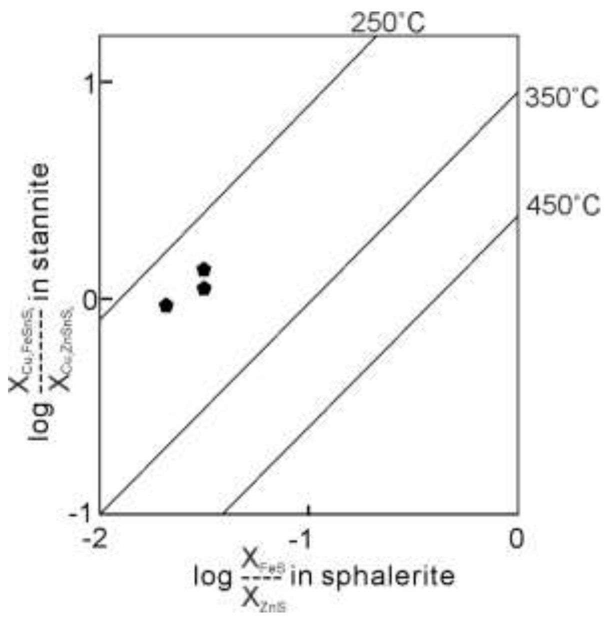

Figure 5: Stannite-sphalerite geothermometric diagram showing the ore-forming temperature of Mosakhee

Implications for Sn-W Exploration

Combined with the previous data (Aung Zaw Myint et al., 2017, 2018), exploration targeting for Sn-W mineral deposits in the Mawchi Sn-W region should meet the following parameters:

(i) Only tourmaline is the indicator mineral of the Sn-W mineralization, although fluorite is found at the Mawchi deposit.

(ii) The N-S fracture system is the most favorable site to host the mineralization.

Conclusions

Mosakhee prospect of the Mawchi Sn-W region is the first stannite-kesterite occurrence in Myanmar. The source of sulfur was slightly contaminated in the formation of sulfides by adding sedimentary sulfur; it is hard to discriminate the contaminated source of sulfur. Ore fluid is mainly derived from the mixing of moderate temperature and low salinity magmatic descent fluid with cooler and more saline meteoric water.

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