Journal of Earth Science, *Vol. 30*, *No. 1*, *p. 70–79*, *February 2019* *ISSN 1674-487X*
Printed in China
https://doi.org/10.1007/s12583-018-0860-y

Timing and Source of the Hermyingyi W-Sn Deposit in Southern Myanmar, SE Asia: Evidence from Molybdenite Re-Os Age and Sulfur Isotopic Composition

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ABSTRACT: The Hermyingyi W-Sn deposit, situated in southern Myanmar, SE Asia, is a typical quartz-vein type W-Sn deposit. The ore-bearing quartz veins are mainly hosted by the Hermyingyi monzogranite which intruded into the Carboniferous metasedimentary rocks of Mergui Series. According to mineral assemblages and crosscutting relationships, four ore-forming stages are recognized: (1) silicate-oxide stage; (2) quartz-sulfide stage; (3) barren quartz vein stage; (4) supergene stage. Five molybdenite samples from the deposit yield Re-Os model ages ranging from 67.8±1.6 to 69.2±1.6 Ma (weighted mean age of 68.7±1.2 Ma), and a well-defined isochron age of 68.4±2.5 Ma (MSWD=0.18, 2σ). This Re-Os age is consistent with the previously published zircon U-Pb age of the Hermyingyi monzogranite (70.0±0.4 Ma) (MSWD=0.9, 2σ) within errors, which indicates a genetic link between the monzogranitic magmatism and W-Sn mineralization. The new high-precision geochronological data reveal that the granitic magmatism and associated W-Sn mineralization in southern Myanmar took place during the Late Cretaceous (70–68 Ma). The extremely low Re contents (22.9 ppb to 299 ppb) in molybdenite, coupled with sulfide δ^{34}S values in the range of +1.9‰ to +5.6‰ suggest that ore-forming metals were predominately sourced from the crustal-derived granitic magma.

KEY WORDS: Hermyingyi W-Sn deposit, molybdenite Re-Os dating, sulfur isotopes, Myanmar, SE Asia.

0 INTRODUCTION

Southeast Asia is composed mainly of a collage of allothigenous continental blocks (Fig. 1a; Metcalfe, 2013; Barber and Crow, 2003), together with volcanic arcs/back-arc basins that have rifted from the northwestern Gondwana margin during the Paleozoic to Mesozoic in response to the closure and opening of three successive Tethyan Oceans (Zaw et al., 2014; Metcalfe, 2013). A most prominent geological signature of SE Asia during the Mesozoic is the W-Sn metallogenic belt that has been of historical importance to the tin-tungsten production in the world (Schwartz et al., 1995). The W-Sn metallogenic belt is N-S trending 2 800 km long and 400 km wide that extends from Myanmar and Thailand to Peninsular Malaysia and Indonesian tin islands (Schwartz et al., 1995). The ore deposits within the belt are dominated by Sn mineralization with locally significant W-dominant mineralization, which have been considered to be closely linked with the Mesozoic granites distributed in the region (Hutchison and Taylor, 1978). However, detailed geochronological and geochemical studies on W-Sn mineralization and related granites are scarce and have hampered our understanding of the ore genesis and its link with the granitic magmatism.

The Hermyingyi W-Sn deposit in southern Myanmar is a typical quartz vein type W-Sn deposit that contains about 622 000 t of ore (WO_3+Sn) with a combined grade of 0.35 %. It was discovered in 1909, with systematically exploration commencing in 1911, and has been a major tin-tungsten producer in the world until World War II. However, only a few field investigations, geochronological and geochemical as well as fluid inclusion studies have been conducted in such a centuried ore deposit (Jiang et al., 2017; Zaw, 1978). Precise age constraint is fundamental to the understanding of ore genesis and related geological processes. The recent zircon U-Pb age determination revealed that the monzogranite related to W-Sn mineralization

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Manuscript received July 18, 2018.
Manuscript accepted October 11, 2018.

Jiang, H., Jiang, S.-Y., Li, W. Q., et al., 2019. Timing and Source of the Hermyingyi W-Sn Deposit in Southern Myanmar, SE Asia: Evidence from Molybdenite Re-Os Age and Sulfur Isotopic Composition. *Journal of Earth Science*, 30(1): 70–79. https://doi.org/10.1007/s12583-018-0860-y. http://en.earth-science.net

of the Hermyingyi deposit was emplaced at 70.0±0.4 Ma (Jiang et al., 2017), but the age of W-Sn mineralization is still poorly constrained. Molybdenite has high contents of Re and negligible initial or common ^{187}Os which make it an ideal mineral for Re-Os dating (Stein et al., 2001, 1998) and it has been widely used to constrain the mineralization ages of a variety of ore deposits including W-Sn deposits in South China (Yang et al., 2017; Zhang X B et al., 2017; Zhang Z et al., 2017; Zhao et al.,

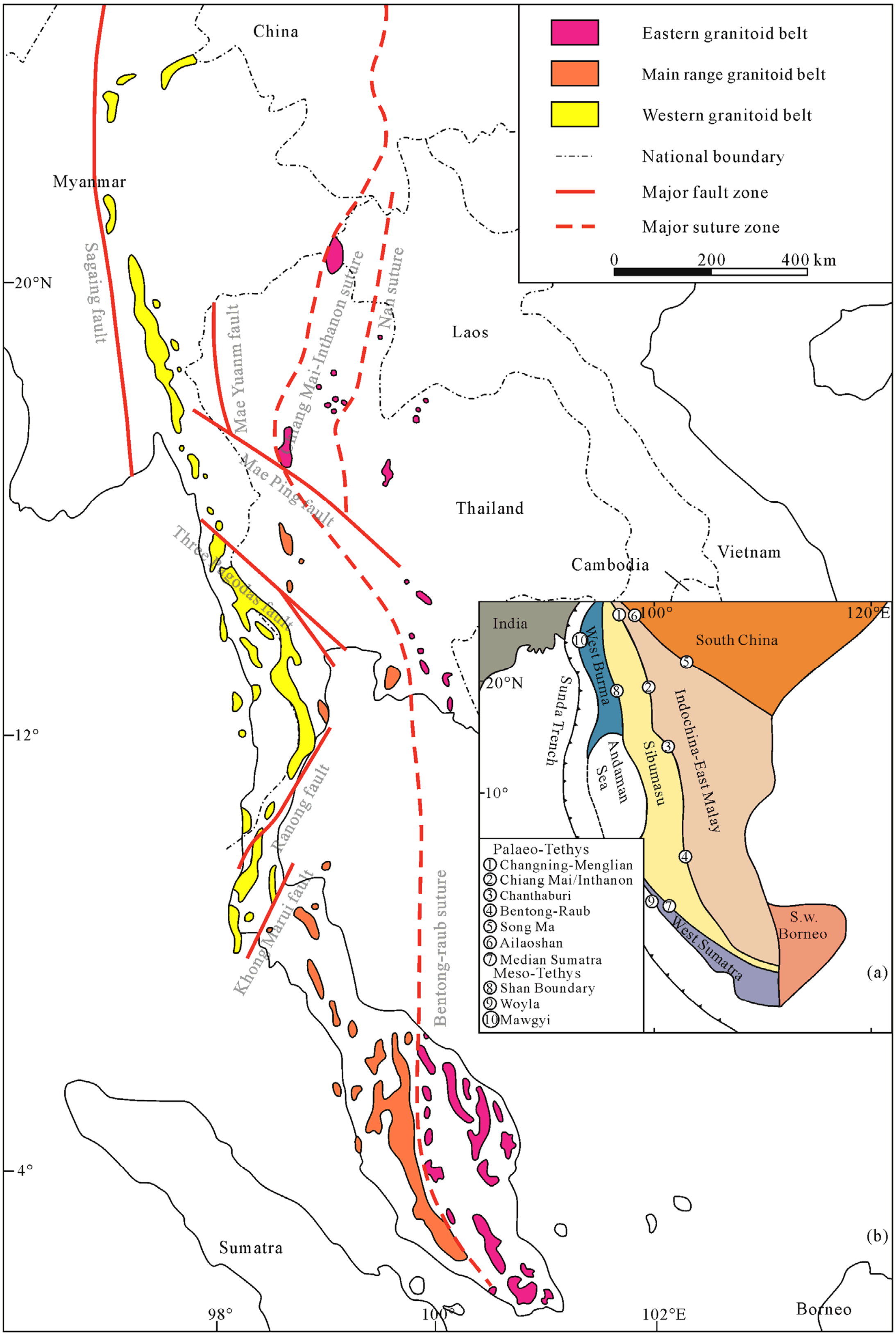

Figure 1. (a) Distribution of principal continental blocks and sutures of SE Asia (after Metcalfe, 2013; Hall, 2002); (b) a schematic map showing the tin-tungsten bearing granitoid provinces of SE Asia with major sutures and faults (after Sone and Metcalfe, 2008; Cobbing et al., 1986).

2017; Hu et al., 2012; Feng et al., 2011; Peng et al., 2006). In this contribution, we report the Re-Os age of molybdenite and sulfur isotopic compositions of sulfide minerals from the Hermyingyi W-Sn deposit for the first time, with the aim of constraining the mineralization age and elucidating the association of W-Sn mineralization with the granites in the Hermyingyi deposit.

1 GEOLOGICAL BACKGROUD

Three sub-parallel Mesozoic granite provinces, which are closely associated with the tin-tungsten belt, have been delineated in SE Asia (Fig. 1b; Schwartz et al., 1995; Cobbing et al., 1986). The Eastern Province, to the east of the Bentong-Raub suture, includes granites that stretch from NW Laos through Chiang Mai in Thailand and southerly into East Malay Peninsula, whereas the Main Range Province is located west of the Bentong-Raub suture that is characterized by granitic gneiss, migmatite and granites (Schwartz et al., 1995; Cobbing et al., 1986). The Western Province, as suggested by Cobbing et al. (1986), customarily refers to the granites which extend from Phuket in Peninsula Thailand northwards into Mogok in central Myanmar, and which may be correlated with the Tengliang granite belt distributed further north in the Tengchong Block, western Yunnan (Hou et al., 2007).

Myanmar can be roughly divided into three main tectonic domains: Indo-Burma Ranges, West Burma Block and Sibumasu Block. The West Burma and Sibumasu blocks are located in the west and east of the Sagaing fault, respectively (Fig. 2). The Indo-Burma Ranges has been interpreted as the suture zone separating the Indian Plate from the West Burma Block, which contains Cretaceous–Eocene marine sedimentary rocks, mélange and turbidites (Allen et al., 2008; Mitchell, 1993). To the east of the Indo-Burma Ranges, the West Burma Block consists of the Wuntho-Popa arc and Cenozoic sedimentary basins (Mitchell et al., 2012; Mitchell, 1993). The Sibumasu Block in Myanmar, bounded to the west by the N-S striking dextral strike-slip Sagaing fault (Khan et al., 2017; Barber and Crow, 2009), is composed of Cambrian to Triassic sedimentary rocks structurally overlying Precambrian metamorphic rocks, which, in turn, are unconformably overlain by Upper Jurassic–Lower Cretaceous red beds with angular unconformity (Searle et al., 2007; Oo et al., 2002).

Southern Myanmar is rich in W-Sn resources, with more than 120 ore deposits or occurrences within a N-S trending belt that stretches from the Myeik Archipelago northwards east of Yangon (Gardiner et al., 2016). The ore types of W-Sn mineralization include quartz vein type (Hermyingyi, Zaw, 1978), greisen type (Mawchi, Zaw and Khin Myo Thet, 1983; Pennaichaung, Zaw, 1984), stratabound type (Yetkanzintaung, Zaw, 1984), and alluvial/eluvial type (Heinda), among which the quartz vein type is of most importance. The quartz vein type W-Sn deposits generally occur in close proximity to the granites in the "MMM" belt (Jiang et al., 2017; Gardiner et al., 2015), part of the Western Province (Schwartz et al., 1995; Cobbing et al., 1986). W-Sn mineralization is mainly hosted in quartz veins and occurred along the exo- and endo-contacts of granites, at the apical zones of granitoid intrusions or in the adjacent sedimentary rocks.

2 GEOLOGY OF THE HERMYINGYI W-SN DEPOSIT

The Hermyingyi W-Sn deposit (Latitude 14°14′N, longitude 98°21′E) is located at approximately 40 km northeast of Tavoy Township, Tennasserim Division, southern Myanmar (Fig. 3). The Mergui Series forms the sole country rock for the deposit. It is composed of Upper Carboniferous to Lower Permian unfossiliferous metasedimentary rocks that strike NNW-SSE with steep easterly dips and are dominated by very thick intervals of argillaceous with minor limestone, quartzite and volcanic detritus. The Mergui Series is intruded by the Hermyingyi monzogranite dated at ca. 70 Ma. According to Jiang et al. (2017), the Hermyingyi monzogranite is composed of plagioclase, K-feldspar, quartz, muscovite and biotite, with accessory amounts of garnet, apatite, ilmenite and fluorite; on the basis of the geochemical and isotopic signatures, they suggest that the Hermyingyi A-type granite is derived from crustal melting of ancient basement rocks.

According to Zaw (1990), more than 300 major and branching veins have been explored in the Hermyingyi deposit. Among them, about 60 quartz veins have been mined out and only 15 major ore veins are productive at present. The deposit has been developed by main crosscuts in five levels, but current mining levels are concentrated on 154 and 100 m because the adits above 154 m level have all collapsed and become inaccessible. These productive veins strike N-S or NNW-SSE with steep easterly dips of 80°–85°, although some west dipping veins are occasionally noted. The veins vary from several centimeters to 2 m in thickness and some veins can be over 200 m in length. Most quartz veins occur in the cupola of the granite, occasionally intersect the contact with the country rock and penetrate the adjacent metasedimentary rocks for short distances. The analogous strikes and no evidence of crosscutting or overlapping of the major ore veins may imply that a single fluid activity contributed to the formation of the Hermyingyi deposit. The ore minerals mainly include wolframite, cassiterite, molybdenite, pyrite, galena, sphalerite, and chalcopyrite with subordinate scheelite, bornite and cosalite. The gangue minerals mainly include quartz, muscovite, lithium mica, topaz and fluorite. Hydrothermal alteration is well-developed, including greisenization and silicification (Figs. 4a, 4b).

According to mineral assemblages and crosscutting relationships, four paragenetic stages are recognized. The silicate-oxide stage (I) formed earliest and is marked by the presence of feldspar, quartz, wolframite, cassiterite and molybdenite (Figs. 4a, 4b, 4c and Fig. 5). The second stage is the quartz-sulfide stage (II) that followed and cross cut the early silicate-oxide stage, and is composed mainly of pyrite, molybdenite, chalcopyrite, galena, sphalerite and quartz, with minor wolframite (Figs. 4d, 4e). Subsequently, the barren quartz vein stage (III) is dominated by quartz, with some fluorite and muscovite (Fig. 4f). The supergene stage (IV), as represented by tungstite and malachite, is the fourth stage which may have resulted from oxidation of wolframite and chalcopyrite at higher supergene levels.

3 SAMPLING AND ANLYTICAL METHODS

3.1 Molybdenite Re-Os Dating

Five molybdenite samples from the silicate-oxide stage were collected at the 154 m mining level underground. The molybdenite occurs primarily as lamellar or tabular minerals in quartz veins, intergrown with wolframite and cassiterite (Fig. 5). The molybdenite separates were magnetically separated and then carefully handpicked under a binocular microscope to achieve >99% sample purity. Subsequently, the selected separates were crushed in an agate mortar to about 200 meshes. Re-Os isotope analyses of molybdenite were performed using ELAN DRC-e ICP-MS at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang. The improved Carius tube method was used for digesting molybdenite separates owing to the extremely low Os concentrations in molybdenite (Shirey and Walker, 1995). Detailed analytical procedures were documented in Du et al. (2004), Li et al. (2010) and Qi et al. (2010).

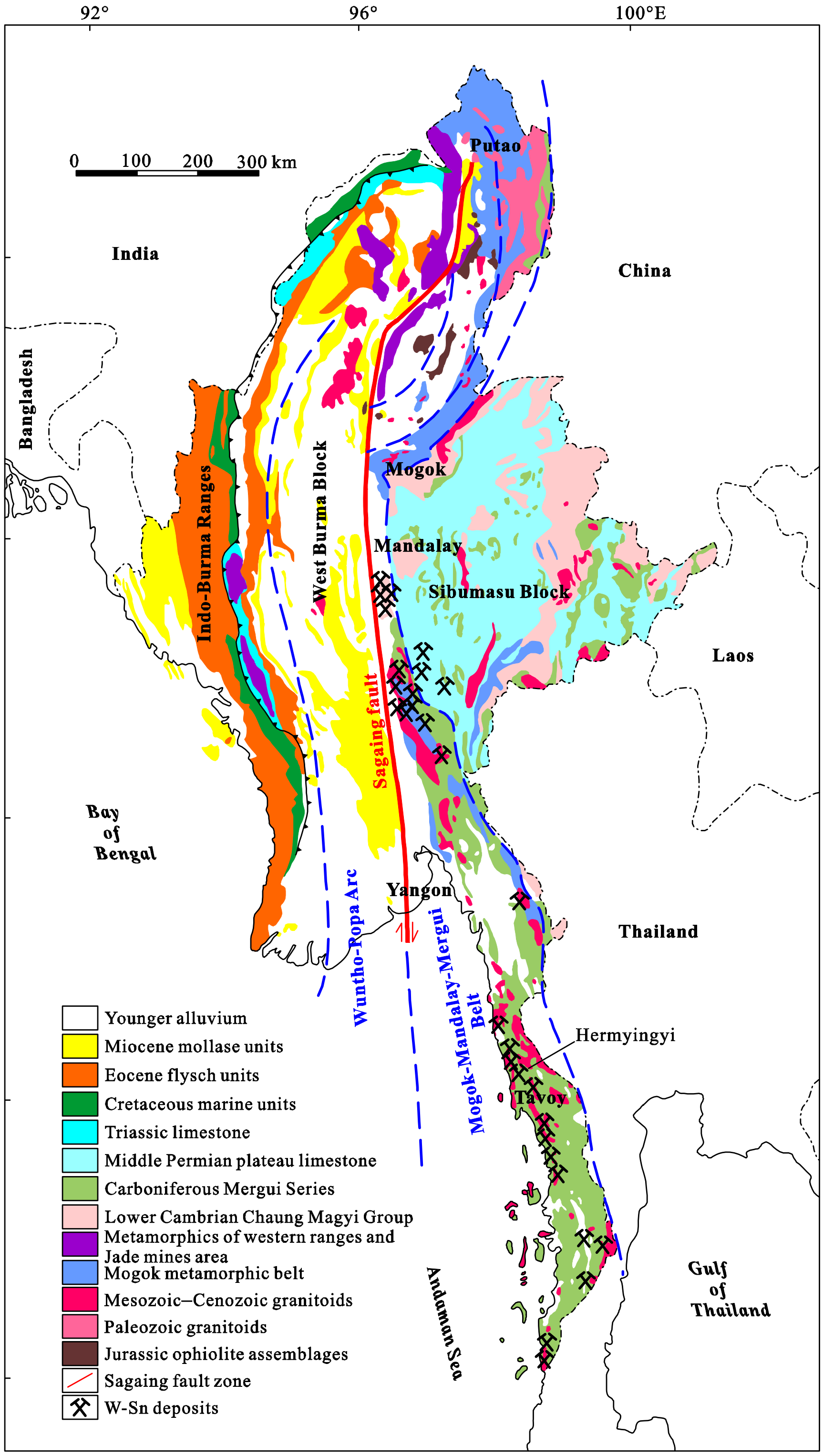

Figure 2. Simplified geological map showing major blocks, major W-Sn deposits and the granitoid belts of Myanmar (after Jiang et al., 2017; Gardiner et al., 2014; Zaw, 1990).

The equation: t=[ln (1+^{187}Os/^{187}Re)]/λ has been used to calculate the model ages, where λ is the decay constant of ^{187}Re of 1.666×10^{-11}/yr^{-1} (Smoliar et al., 1996). The Re-Os isochron age was calculated following the least squares method of York (1968), as implemented in Isoplot/Ex_ver3 (Ludwig, 2003).

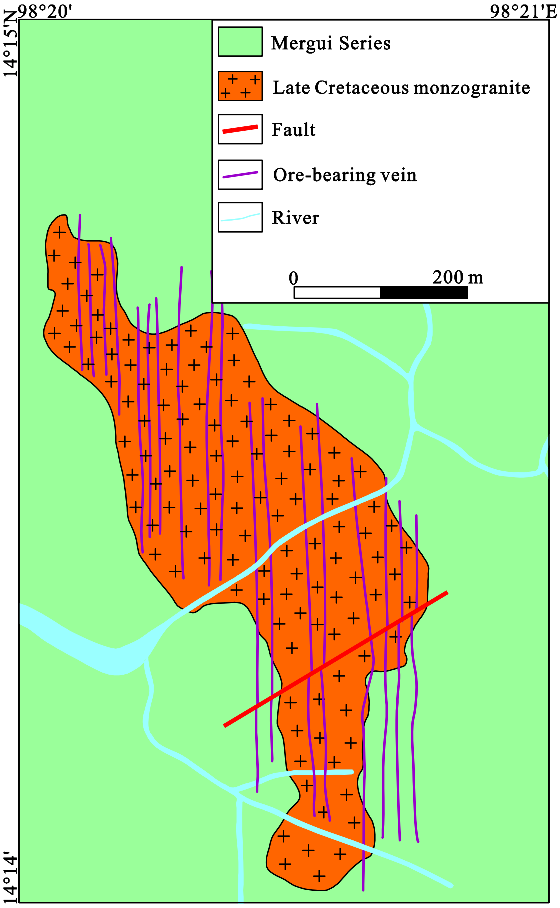

Figure 3. Geological map of the Hermyingyi W-Sn deposit.

3.2 Sulfur Isotope Analysis

Sulfur isotope analyses were performed for 18 sulfide samples from the quartz-sulfide stage, including four galenas, three sphalerites, four pyrites, four chalcopyrites and three molybdenites. These samples were collected at the 154 and 100 m mining level underground, respectively. The sulfur isotopic analysis were carried out using a continuous flow-isotope ratio mass spectrometry (CF-IRMS) at the State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China. The detailed analytical procedure can be found in Grassineau et al. (2001). The data are reported in standard delta notation relative to VCDT, and the analytical error is ≤ 0.2‰.

4 RESULTS

4.1 Molybdenite Re-Os Age

Five molybdenites are analyzed for their Re-Os isotopes and the results are listed in Table 1 and illustrated in Fig. 6. The Re-Os model ages range from 67.8±1.6 to 69.2±1.6 Ma (weighted mean age of 68.7±1.2 Ma). The calculated isochron age is 68.4±2.5 Ma (MSWD=0.18, 2σ), and the calculated initial ^{187}Os value is 0.000 1±0.001 1 ng/g. A nearly zero intercept confirms that molybdenite contains a negligible amount of common Os and that most of the ^{187}Os in molybdenite are radiogenic. The nearly identical Re-Os weighted mean age and isochron age within the uncertainty suggest that the analytical result is reliable and could precisely constrain the timing of the Hermyingyi W-Sn mineralization.

4.2 Sulfur Isotopic Composition

Sulfur isotopic compositions of 18 sulfides are presented in Table 2 and illustrated in Fig. 7. The δ^{34}S values of sulfides

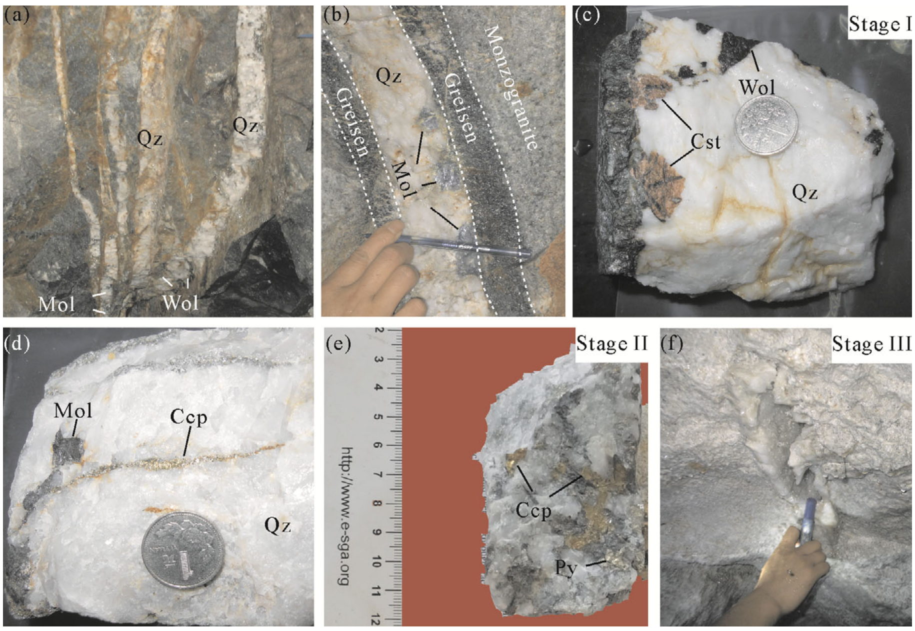

Figure 4. Photographs of ore and gangue minerals. (a) (b) and (c) for ore minerals of the silicate-oxide stage; (d) and (e) for ore minerals of the quartz-sulfide stage; (f) for the barren quartz vein stage. Cst. Cassiterite; Ccp. chalcopyrite; Mol. molybdenite; Py. pyrite; Qz. quartz; Wol. wolframite.

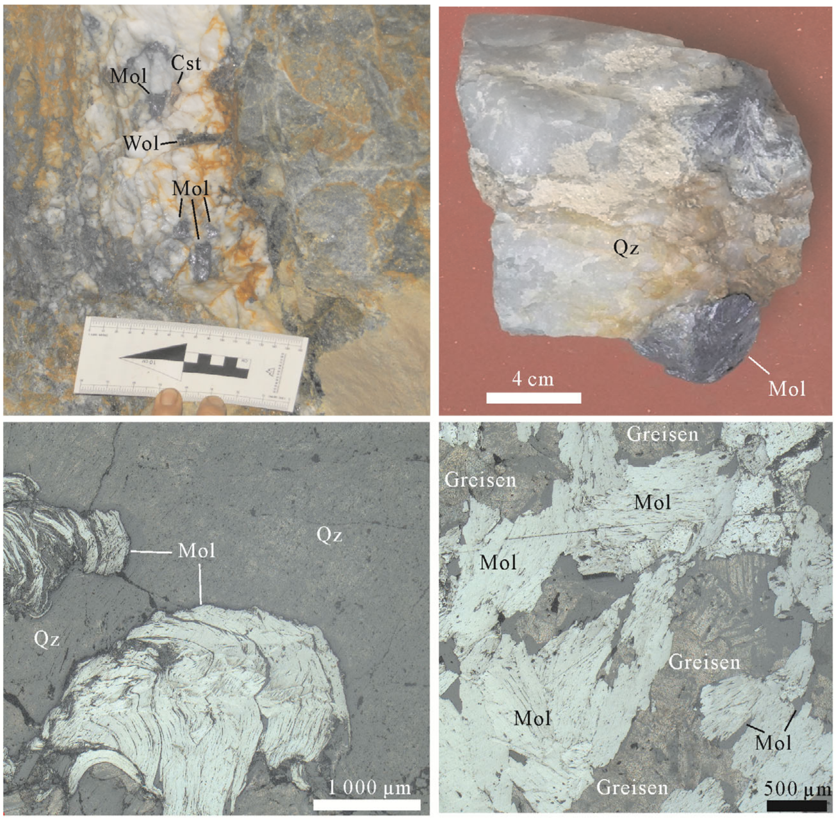

Figure 5. Photographs of molybdenite-bearing ore samples from the Hermyingyi W-Sn deposit.

Table 1 Re and Os isotopic data for molybdenite from the Hermyingyi W-Sn deposit

Sample	Weight (g)	Re (ng/g)		^{187}Re (ng/g)		^{187}Os (ng/g)		Model ages (Ma)	
		Measured	1σ	Measured	1σ	Measured	1σ	Measured	1σ
HMG14	0.043 9	22.92	0.34	14.30	0.10	0.016 39	0.000 46	68.8	1.1
HMG16	0.040 7	69.92	0.86	43.77	0.31	0.049 45	0.000 91	67.8	1.6
HMG17	0.042 3	28.67	0.46	18.84	0.19	0.021 75	0.000 53	69.2	1.6
HMG29	0.044 4	80.34	0.92	65.40	0.41	0.075 15	0.001 41	68.9	1.5
HMG67	0.043 2	298.6	2.5	189.0	0.8	0.216 7	0.007 1	68.8	1.3

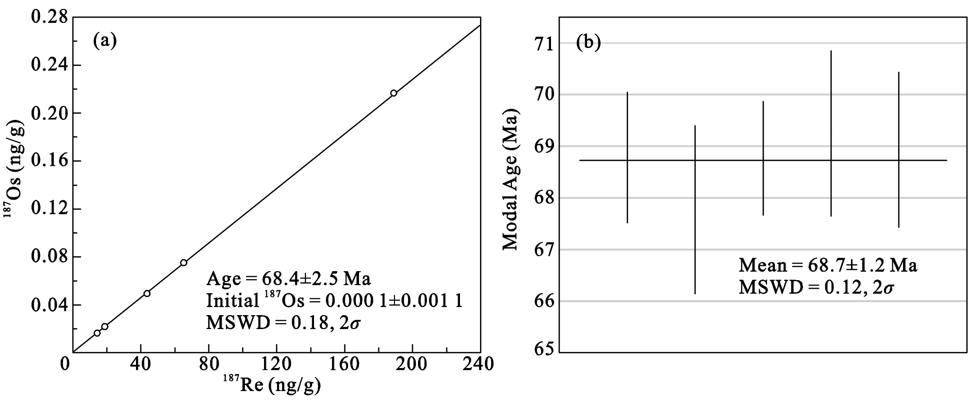

Figure 6. (a) Re-Os isochron age and (b) weighted mean model age of molybdenites from the Hermyingyi deposit.

are homogeneous with a narrow range of +1.9‰ to +5.6‰ (average +3.7‰). The δ^{34}S values of four galena separates range from +1.9‰ to +2.8‰ (average +2.5‰); the δ^{34}S values of three sphalerite separates range from +2.9‰ to +3.9‰ (average +3.5‰); the δ^{34}S values of four chalcopyrite separates range from +3.5‰ to +4.3‰ (average +3.8‰); the δ^{34}S values of four pyrite separates range from +3.3‰ to +5.6‰ (average +4.9‰); the δ^{34}S values of three molybdenite separates range

Table 2 The sulfur isotopic composition of the Hermyingyi W-Sn deposit

Sample	Location	Minerals	$\delta^{34}S_{VCDT}$ (‰)
HMG20	Vein 26E at 154 m level	Galena	+2.7
HMG25	Vein 15E at 154 m level	Galena	+2.8
HMG37	Vein 15E at 154 m level	Galena	+2.5
HMG71	Vein 20E at 154 m level	Galena	+1.9
HMG24	Vein 15E at 154 m level	Sphalerite	+3.9
HMG25	Vein 15E at 154 m level	Sphalerite	+3.5
HMG27	Vein 26E at 154 m level	Sphalerite	+2.9
HMG20	Vein 26E at 154 m level	Chalcopyrite	+4.3
HMG31	Vein 20E at 154 m level	Chalcopyrite	+3.5
HMG35	Vein 20E at 100 m level	Chalcopyrite	+3.7
HMG38	Vein 24E at 154 m level	Chalcopyrite	+3.8
HMG20	Vein 26E at 154 m level	Pyrite	+5.6
HMG22	Vein 14E at 154 m level	Pyrite	+5.3
HMG31	Vein 20E at 154 m level	Pyrite	+3.3
HMG35	Vein 20E at 154m level	Pyrite	+5.6
HMG36	Vein 14E at 154 m level	Molybdenite	+3.7
HMG34	Vein 13E at 100 m level	Molybdenite	+3.6
HMG68	Vein 13E at 100 m level	Molybdenite	+3.9

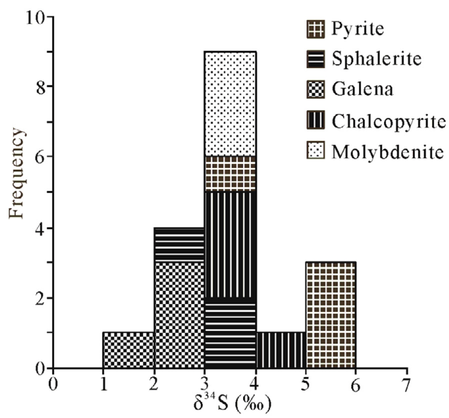

Figure 7. Sulfur isotope histogram of the Hermyingyi W-Sn deposit.

from +3.6‰ to +3.9‰ (average +3.7‰).

5 DISCUSSION

5.1 Age of the Hermyingyi W-Sn Deposit

The recent zircon U-Pb age determination revealed that the monzogranite related to W-Sn mineralization of the Hermyingyi deposit was emplaced at 70.0±0.4 Ma (MSWD=0.9, 2σ) (Jiang et al., 2017). However, no accurate mineralization age has been reported for the Hermyingyi W-Sn deposit prior to this study. In the Hermyingyi W-Sn deposit, homogenization temperatures of fluid inclusions from vein quartz and quartz in the adjacent greisens range from 186 to 250 ºC (Zaw, 1978), which are significantly lower than the estimated closure temperature of 500 ºC for the Re-Os isotopic system (Suzuki et al., 1996). In addition, the molybdenite samples were selected from the ore-bearing quartz veins at the silicate-oxide stage (Fig. 5). Wolframite, when presented, is generally the first ore mineral to crystallize, followed by molybdenite and cassiterite. Thus, it can be assumed that the Re-Os system for molybdenite remained closed during and after mineral precipitation which could be less easily disturbed by later hydrothermal overprinting (Stein et al., 2001, 1998). The molybdenite Re-Os isochron age of 68.4 Ma could represent the mineralization age of the Hermyingyi deposit.

5.2 Possible Source of Ore-Forming Metals

According to Ohmoto (1972), the interpretation of the sulfur source of hydrothermal deposit must be dependent on the total sulfur isotopic composition of hydrothermal fluids ($\delta^{34}S_{\Sigma}$) and physico-chemical parameters of the fluid system. Under a reduced deposition environment that is characterized by low pH and oxygen fugacity (fo_2), the fluid system is dominated by H_2S and the sulfide $\delta^{34}S$ could approximate the hydrothermal fluid $\delta^{34}S$ in the equilibrium state (Ohmoto, 1972). The ore minerals from the Hermyingyi deposit have simple sulfide assemblages, including galena, sphalerite, chalcopyrite, pyrite and molybdenite, but sulfate minerals are scarce, implying a reduced system for the deposition of sulfides. The $\delta^{34}S$ values in each coexisting mineral assemblage (HMG20, HMG25, HMG35) decrease progressively in the sequence of molybdenite-pyrite-sphalerite-chalcopyrite-galena, suggesting that a sulfur isotopic fractionation equilibrium had been reached (Ohmoto, 1972). Therefore, the sulfide $\delta^{34}S$ could represent the hydrothermal fluid $\delta^{34}S$. The $\delta^{34}S$ values of sulfides from the Hermyingyi deposit are homogenous and vary from +1.9‰ to +5.6‰, with an average of 3.7‰, indicating a magmatic source. These values are in well agreement with the contention of Ohmoto and Rye (1979), who suggested that the magmatic-hydrothermal ore deposits related with felsic intrusions which are derived from a homogenized continental crust have a $\delta^{34}S$ range of +0.2‰ to +5.8‰.

The Re-Os isotopic system is generally regarded as a highly sensitive indicator for the source of ore-forming metals (Stein et al., 2001; Mao et al., 1999). Previous studies have demonstrated that Re contents in molybdenite display a monotonic decreasing trend from >100 ppm for a mantle source, through tens of ppm for a mixed source of mantle and crust, to <10 ppm for a crustal source (Berzina et al., 2005; Mao et al., 1999). As shown in Table 1, Re contents in molybdenite from the Hermyingyi deposit vary from 22.9 ppb to 299 ppb, with an average of 100 ppb, and are similar to values obtained from typical quartz vein type tin-tungsten deposits in South China for which a crustal source of ore metals are assumed (e.g., Zheng et al., 2017; Zhang et al., 2015; Hu et al., 2012; Feng et al., 2011; Peng et al., 2006). In addition, the Hermyingyi monzogranites have negative $\varepsilon_{Nd}(t)$ (-11.3 to -10.6) and $\varepsilon_{Hf}(t)$ (-12.4 to -10.0) values, with Paleoproterozoic T_{DM2} ages (1.7–1.9 Ga) for both Nd and Hf isotopes, indicating that they were derived from partial melting of the Paleoproterozoic continental crust with no or little mantle component (Jiang et al., 2017). Therefore, it is suggested that the ore-forming metals from the Hermyingyi deposit were predominantly magmatic and are related to the granitic intrusion.

5.3 Regional Metallogenic Implication

According to the aforementioned discussion, the Re-Os isochron age in this study and previously published zircon U-Pb age of the Hermyingyi monzogranite are nearly identical (70.0±0.4 Ma; Jiang et al., 2017), in addition, the occurrence of the ore veins is in close proximity to the Hermyingyi monzogranite and the relatively narrow range of $\delta^{34}S$ values of sulfides coupled with the low Re contents in molybdenite, we suggest for a genetic link between the W-Sn mineralization and the emplacement of the Hermyingyi monzogranite in the Hermyingyi deposit.

Previous studies have demonstrated that the granites within the Western Province of SE Asia are mainly distributed in central and southern Myanmar (e.g., Charusiri et al., 1993). The recent zircon U-Pb age determinations show that the granitic magmatism in central and southern Myanmar mainly occurred within a relatively wide age range of 130–45 Ma (Jiang et al., 2017; Than Htun et al., 2017; Gardiner et al., 2017, 2016; Mitchell et al., 2012; Barley et al., 2003). Among them, the W-Sn mineralized granites yield Late Cretaceous–Paleogene ages of 75–45 Ma (Jiang et al., 2017; Than Htun et al., 2017; Gardiner et al., 2017, 2016). In addition, the Late Cretaceous–Paleogene W-Sn deposits and related granites have been recently identified from the Tengliang granite belt in Tengchong Block, western Yunnan, which has been regarded as the northern continuation of the Western Province (Hou et al., 2007). Ma et al. (2013) obtained a cassiterite U-Pb age of 75.5±2.6 Ma for the Dasongpo Sn deposit. Chen et al. (2014) reported cassiterite U-Pb ages from the Tieyaoshan, Xiaolonghe and Lailishan Sn deposits of 119.3±1.7, 71.9±2.3, and 47.4±2.0 Ma, respectively. The zircon U-Pb dates of 73.3±0.5, 52.7±0.3 and 53.0±0.4 Ma were also reported for the Xiaolonghe and Lailishan granites, respectively (Chen et al., 2015). Integrating our new geochronological study with the high precise geochronological data published previously, it may imply an important regional W-Sn mineralization event related to Late Cretaceous–Paleogene granitic magmatism in the Western Province of SE Asia. Of course, more precise geochronological studies in the region are needed to confirm this assumption.

It is noteworthy that South China, which is located in the vicinity of SE Asia, hosts abundant Late Cretaceous granitoids (110–75 Ma, mostly 95–80 Ma) and associated W-Sn deposits (e.g., Zhao et al., 2017; Mao et al., 2013). As argued by Mao et al. (2013) and Zhao et al. (2017), the Cretaceous polymetallic W-Sn mineralization (134–80 Ma) also represents a significant episode of W-Sn metallogenic events in South China. Liu et al. (2007) obtained a cassiterite U-Pb age of 82.0±9.6 Ma for the Dulong Sn deposit. Yang et al. (2008) reported a molybdenite Re-Os age of 83.4±2.1 Ma for the Gejiu Sn-Cu deposit. More recently, Zheng et al. (2017) obtained a molybdenite Re-Os age of 79.4±1.1 Ma for the Xishan W-Sn deposit, western Guangdong Province, consistent with the zircon U-Pb age of 79.1±0.3 Ma for the alkali feldspar granite. These available geochronological data suggest that the W-Sn mineralization and related granitic magmatism in the Western Province of SE Asia took place obviously younger than those in South China. Why are there so many large-sized Late Cretaceous–Paleogene W-Sn deposits in SE Asia and what was the geodynamic setting for their formation? Whether there also exists a latest Cretaceous or younger W-Sn metallogenic event in South China? The solutions to these questions are of great scientific and economic importance and need numerous systematic further studies in the future.

6 CONCLUSIONS

(1) Re-Os dating of five molybdenites yield model ages varying from 67.8±1.6 to 69.2±1.6 Ma, with a weighted mean age of 68.7±1.2 Ma, in consistent with a well-defined $^{187}Re/^{187}Os$ isochron age of 68.4±2.5 Ma (MSWD=0.18, 2σ). The nearly identical Re-Os isochron age and previously published zircon U-Pb age of the Hermyingyi monzogranite (70.0±0.4 Ma) (MSWD=0.9, 2σ) indicate a genetic link between the monzogranitic magmatism and W-Sn mineralization. Our new high precise geochronological data reveal that W-Sn mineralization and related granitic magmatism took place during the Late Cretaceous (70–68 Ma).

(2) The low Re contents (22.9 ppb to 299 ppb) in molybdenite, coupled with $\delta^{34}S$ values in the range of +1.9‰ to +5.6‰ of sulfides suggest that ore-forming metals were predominately magmatic related to the crust melting of granites.

ACKNOWLEDGMENTS

This study is financially supported by the National Key R&D Program of China (No. 2017YFC0602405), the National Natural Science Foundation of China (Nos. 41503043, 91755208), and the MOST Special Fund from the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (No. MSFGPMR03-2). We are very grateful to Tenwin-Pacific Brothers Mining Services Company Limited for field assistance. Special thanks are extended to two anonymous reviewers for their constructive comments and suggestions. The final publication is available at Springer via https://doi.org/10.1007/s12583-018-0860-y.

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