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GEOLOGICAL, GEOCHRONOLOGICAL AND FLUID-INCLUSION STUDIES OF THE TIN AND TUNGSTEN MINERALIZATION OF THE MAE LAMA-TAE SONG YANG AREA, NORTHERN THAILAND

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ABSTRACT

Geological and $^{40}Ar/^{39}Ar$ geochronological investigations reveal that tin-tungsten mineralization in the Mae Lama-Tae Song Yang mining district is coeval with related granitoid rocks, both occurring during Late Cretaceous (ca. 70 Ma at Mae Lama) and Middle Eocene (ca. 45-46 Ma at Tae Song Yang). The ages of the granitoids and mineralization at Mae Lama are markedly contrast to those reported earlier by Beckinsale et al. (1979) who considered the emplacement age of granitoids at ca. 130 Ma (using Rb-Sr whole-rock isochron technique) and the age of mineralization at ca. 70 Ma (using K-Ar technique). The granitoid rocks are inferred to be highly-evolved, peraluminous, S-type and ilmenite-series, syenogranite. The $^{40}Ar/^{39}Ar$ age information also indicates that the north-trending Mae Hong Son Fault was active during the Oligocene-Miocene boundary (ca. 23 Ma).

The Mae Lama-Tae Song Yang mineralization is also considered to have been related to the displacement along the northwest-trending Mae Ping Fault. The As content of arsenopyrite and the fluid-inclusion microthermometric analyses show that the main wolframite and cassiterite mineralization was precipitated from predominantly temperatures of ca. 300-425° C and under pressure probably not exceeding 2 kbar. The late stage-scheelite mineralization formed at a broadly similar temperature and, probably, pressures (ca. 0.07 to 1.4 kbar) but from C-bearing fluids. Secondary fluid inclusions observed in the Mae Lama veins may have been trapped by the movement on the Mae Hong Son Fault at the temperatures of ca. 210-200° C.

INTRODUCTION

The Mae Lama-Tae Song Yang mining district (Fig. 1) is located close to the northwestern extremity of the country, extending from Amphoe Mae Sariang, Changwat Mae Hong Son, to Amphoe Tae Song Yang, Changwat Tak. Three currently operating mines are selected for this

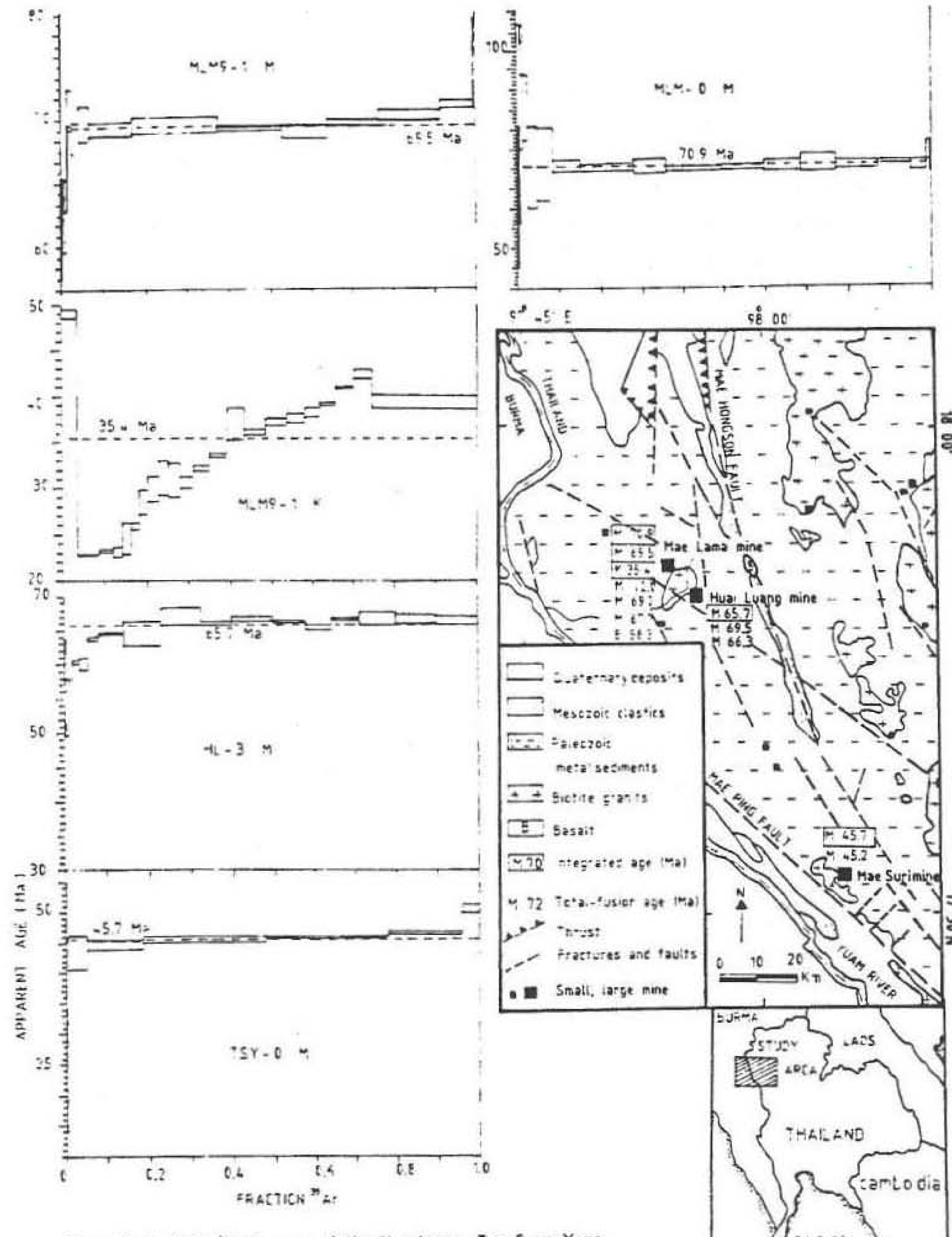

Fig. 1. Geological sketch-map of the Mae Lama - Tae Song Yang mining area, after Charusiri (1989), and showing the locations of the studied mines and the distribution of Sn - W deposits, the Ar40/Ar39 dates, and the age spectra. (N.B. M = musovite; K = potash feldspar).

Figure 1. Geological sketch-map of the Mae Lama - Tae Song Yang mining area, after Charusiri (1989), and showing the locations of the studied mines and the distribu tion of Sn-W deposits, the ^{40}Ar / ^{39}Ar dates, and the age spectra. (N.B.M. = muscovite; K = potash feldspar).

study: the Mae Lama tungsten (-tin) and the Huai Luang tin (-tungsten) deposits in the Mae Lama district; and the Mae Surie tin (-tungsten) deposit of the Tae Song Yang area. The geology and ore deposits of the Mae Lama district have been described by Teggin and Suensilpong (1973), Suensilpong (1975) and, in most detail, Pitragool and Panupaisal (1979) and Charusiri (1989).

The region is underlain by Lower Paleozoic metasediments of the Tarutao and Thung Song Groups, which are locally unconformably overlain by clastic sediments of the Mesozoic Khorat Group. Several north-trending Cenozoic intermontane basins contain thick sequences of continental clastics. The granitoid rocks intrude only the Lower Paleozoic strata. The area displays two major fault-zones: one with a northwest-southeast trend, named the Mae Ping Fault (Bunopas, 1981); the other, associated with thrusting (Baum et al., 1979), and with a north-south strike, is referred to herein as the Mae Hong Son Fault. The precise ages of displacement along these structures are unknown, but movement both in the Tertiary (Suensilpong, 1975), and Quaternary (Baum et al., 1970) is probable.

GEOLOGY AND W-Sn MINERALIZATION

The *Mae Lama* W(-Sn) deposit is situated in the immediate exocontact zone of the Mae Lama, or Doi Nopparat, granitoid stock. The Mae Lama stock, (7 km diameter), intrudes both clastic and non-clastic sedimentary strata of Cambrian to Ordovician age. These are regionally metamorphosed to marbles, calc-silicate rocks, slates and schists. A southeast-to-northwest traverse across Doi Nopparat between an elevation of 320 m above mean sea level and the mine (995 m) indicates that the intrusion shows a progressive, upward transition from a porphyritic biotite (± muscovite) granite along the Mae Nam Yuam to a weakly porphyritic, more muscovite-rich, leucogranite at the mine. There is no doubt that this is a single intrusion. The roof zone near the deposit exhibits considerable textural variability, with aplitic and pegmatitic domains, the latter commonly of lensoid, small-stock, or vein form.

Petrographically, the granites in the immediate mine area are medium- to coarse-grained and display extensive alteration. Biotite is mainly altered to chlorite. Primary muscovite is characteristic, but secondary muscovite are more common. However, the petrographic evidence for the late-stage (i.e., post-muscovite) growth of both albite and microcline suggests that the granite of this area has experienced alkali metasomatism. Chemical analyses (Charusiri, 1989) reveal that all the rocks are peraluminous, with an average alumina to alkalis ratio (A/CNK) of 1.2. The petrological and geochemical investigation reveal that the Mae Lama granite is both highly evolved and with distinct S-type affinities. Assignment of the granites to the ilmenite series of Ishihara (1977) is supported by the absence of magmatic magnetite and the low Fe^{+3} : Fe^{+2} ratios of the rocks (Charusiri, 1989).

A 50 cm sphalerite-fluorapatite-quartz-muscovite vein cuts the main vein, but the temporal relationship between this and the late-stage scheelite fluorite-calcite-quartz vein is uncertain. In some areas, the main quartz W-vein is extensively brecciated along its walls. A 60 cm dyke of aplite cuts the fluorite-rich scheelite veins in the western part of the adit, demonstrating overlapping temporal relationships between the granitoid rocks and mineralization. At the southern boundary of the Mae Lama concession (175 m from the main adit portal), cassiterite and minor wolframite have been recovered from northwest - trending pegmatites and quartz veins cutting (meta) sandstone and siltstone.

The *Huai Luang* deposit, the most important source of cassiterite in the study area, is located on the steep eastern bank of the Mae Nam Yuam, about 4.5 km east of Mae Lama mine. The deposit occurs at the eastern contact of the Mae Lama stock. The country-rocks comprise marble and recrystallized, laminated limestones in the upper part of the sequence and slates in the lower. The granitoid rocks are fine- to medium-grained, in part aplitic, leucogranites, containing more than 10% muscovite.

Cassiterite was derived mainly from quartz and pegmatite veins and greisen bodies, and locally from saprolite and residual deposits. The wolframite is generally restricted to quartz veins whereas scheelite is disseminated in the granitoid rocks and locally in pegmatitic and quartz veins. Several tourmaline-muscovite pegmatite-aplite bodies (50 cm - 2 m) occur as sill-like bodies in the carbonate-rich sediments and containing abuntant, discontinuous, wolframite-quartz veins and veinlets, the majority of which do not extend into the country-rocks. The intimate association of aplogranite, pegmatite and quartz veins suggests that they are cogenetic and, and moreover, that the Sn and W mineralizations constitute facies of a single, if complex, episode of hydrothermal activity.

Numerous faults have been observed to cross-cut the ore zones. One north-south fault with extensive gouge and coarse calcite fill displays and apparent displacement of 1-1.5 m. A second set of small faults trends east-north-east and dips steeply to the south. Several veins locally appear markedly distorted by drag adjacent to the faults.

The *Mae Surie* deposit is situated about 35 km northwest of Amphoe Tae Song Yang, Changwat Tak. The deposit occurs in the roof-zone of a granitoid body, referred to herein as the Tae Song Yang stock, which intrudes Cambrian metaclastic rocks, including quartzite, slate, phyllite, and schist (Baum et al., 1970).

The mineralization comprises Sn (-W) - bearing quartz veins, veinlets, greisen bodies and stockworks. The orientations of the ore-bearing veins are irregular, but the majority have a northwest southeast trend. In general, greisen bodies and stockworks yield mainly cassiterite, whereas the quartz veins and veinlets contain abundant wolframite as well as cassiterite.

The granitoid stock is a northwest-southeast - elongated intrusion paralleling the Mae Ping Fault. Charusiri (1989) noted that the stock displays an upward trainsition from a coarse-grained, biotite (± muscovite) granite to fine-grained, muscovite-rich, leucogranite. Alteration, (kaolinization and sericitization) is prominent in the granite, and kaolinite is a by - product of the mining operations.

CONDITIONS OF ORE FORMATION

Previous Date : Reinterpretation

Establishment of the P-T-X- conditions of initial emplacement of the Mae Lama - Huai luang mineralization, and of post-mineralization tectonic events, assume some importance in view of the complex models advanced by Beckinsale et al. (1979) and Kerrich and Beckinsale (1988) to explain the marked discordance between Rb-Sr and K-Ar dates in this district.

Pitragool and Panupaisal (1979) studied the ore petrology of the Mae Lama W-vein, employing the Mg content of calcite, the As content of arsenopyrite, sphalerite - chalcopyrite "exsolution", and fluid inclusions to estimate the temperatures of mineralization, They concluded that the early vein-stage (scheelite-wolframite-cassiterite) formed from 300 to 475°C and late-stage calcite-fluorite assembleges from 300 to 100° C.

Confusion may arise in the interpretation of sphalerite-chalcopyrite intergrowth, as suggested by Hutchison and Scott (1981), Barton (1978) and Roedder (1984). This suggests that temperature-dependant exsolution is not the means by which intergrowths form. Sphalerite-chalcopyrite intergrowths, therefore, do not constitute a good geothermometer (Craig and Vaughan, 1981). Nonetheless, calcite-dolomite equilibrium relationships are widely accepted as a fairly precise geothermometer (Essene, 1983; Perkins et al., 1982). The data of Pitragool and Panupaisal (1979) indicate that the formation temperature of "skarn and sericite rocks" at the mine is about 390 to 420°C. Using Kretschmar and Scott's (1976) pseudobinary T-X section of arsenopyrite stability relationshps along the pyrite-loellingite join, Pitragool and Panupaisal (op. cit) proposed that the arsenopyrite-pyrite assemblage in the Mae Lama wolframite-quartz vein defines a temperature of about 428 to 477°C and "a sulphur activity of 6" (presumably, log aS_2 = -6). It is inferred that the arsenopyrite composition they delimited was between 31.5 and 32.1 atomic % As, and that they employed that univariant curve for the buffered reaction, pyrite + liquid = arsenopyrite.Kretschmar and Scott's research indicates clearly that As activity is not constrained by the assemblage pyrite-arsenopyrite, implying that Pitragool and Panupaisal eroneroulsy applied the phase diagram. However, the apparent coexistence of pyrite, arsenopyrite and pyrrhotite in the vein (Pitragool and Panupaisal, 1979; Charusiri, 1989) also constraians the temperature of the mineralization. Using the equilibrium, arsenopyrite + pyrite = pyrrhotite + liquid (As-S), the analytical data of Pitragool and Panupaisal (op.cit.) yield a temperature range of 395 to 425°C. Thus, the *maximum* temperature of formation of the wolframite-quartz vein is inferred to have been ca. 425°C.

Fluid - Inclusion Data

Charusiri (1989) made a detailed study on fluid inclusions in a sample from the main Mae Lama wolframite-bearing quartz vein (MLM-O), and a specimen from a late-stage scheelite vein in the adit and a sample from a Huai Luang tin-bearing quartz veinlet (HL-3). Inclusions were observed in quartz, apatite, fluorite and scheelite. Twenty-four inclusions hosted by these mineral were examined to determine the temperatures of homogenization (T_h), pressure of formation, and salinities of the ore-forming fluids, using a Chaixmeca heating and cooling stage at Queen's University.

In the Mae Lama deposit, the temperature of homogemization (T_h) of primary two-phase inclusions in early-formed quartz ranged from 242 to 274°C; inclusions of similar type from the Huai Luang mine yielded T_h of 255 to 274°C. The two secondary liquid + vapour inclusions homogenized to liquid at 212-221°C. At Mae Lama, twelve final-melting temperatures (T_m) of the two- phase primary inclusions (0.2 to -4.9°C) indicate that the fluid contains 0.5 to 7.5 equivalent wt % NaCl (Potter et al., 1979). At Huai Luang eight final-melting temperatures of two-phase inclusions (-1.6 to -8.9°C.) correspond to 2 to 12.5 equivalent wt % NaCl. The T_h of six secondary fluid inclusions in Mae Lama vein-quartz sample ranged from 209 to 221°C.

Mixed carbonic/aqueous inclusions were found coexisting with two-phase aqueous inclusions in apatite and fluorite in the scheelite-rich vein at Mae Lama. The inclusions with the T_h of 266 to 272°C. indicate pressures of 0.9 to 1.4 kbar. Salinities of the aqueous liquids in these inclusions, estimated from the final-melting temperature of clathrate-hydrate, ranged from 1 and 4.2% NaCl, according to the data of Collins (1979).

The homogenization temperatures of primary two-phase inclusions in quartz from both Mae Lama and Huai Luang indicate minimum pressures averaging 60 bars, indicating that the early-stage W-vein at Mae Lama and the Sn-vein at Huai Luang formed at over 300°C. If the *maximum* temperature of the wolframite-quartz vein was about 425°C. (see above), the "pressure correction" will be about 150 to 185°C and mineralization occured under *maximum* confining pressure of about 1.7 to 2 kbar (Potter,1977).

It can be concluded that the main wolframite-quartz vein of the Mae Lama mine formed from dilute brines at temperatures of between 300 and 425°C. and at pressures not exceeding 2 kbar. Th late-stage scheelite vein formed at lower temperatures and pressures. Secondary fluid inclusions are inferred to record a subsequent, lower-temperature (215°C), tectonic hydrothermal event.

Although this study yields temperatures of mineralization falling within the overall range estimated by Pitragool and Panupaisal (1979), it is also evident that the subordinate scheelite formed at temperatures higher than they inferred for the late-stage mineralization. The carbonic fluids at the Mae Lama deposit were apparently introduced into the hydrothermal system only during formation of the minor scheelite-fluorite-carbonate veins : the fluids responsible for main stage wolframite deposition apparently contained negligible CO_2 or CH_4.

GEOCHRONOLOGICAL STUDIES

Previous Geochronological Studies

Von Braun et al. (1976) dated muscovite granites from the Mae Lama mine area using both Rb - Sr (whole-rock) and K - Ar (mineral) methods. The whole-rock yielded a Rb - Sr model age of ca.78 Ma. Muscovites from the same samples gave (recalculated) K-Ar ages ranging from 70.0 to 71.2 Ma and biotites from 61.2 to 62.2 Ma. They, however, inferred that the Mae Lama stock was emplaced earlier than the Late Cretaceous (pre - 78 Ma.)

Beckinsale et al. (1979) dated unaltered granites along the Mae Nam Yuam, employing the Rb - Sr whole-rock isochron technique. The rocks yielded an Early Cretaceous age (130 ± 4 Ma), with an inital Sr ratio of 0.7086. The muscovite and biotite K-Ar dates from the same intrusion, however, were ca. 70 and 55 Ma,respectively, leading Beckinsale et al.(1979) to conclude that the granite was intruded at about 130 Ma, but that mineralization occurred at about 70 Ma. They proposed that a Late Cretaceouss hydrothermal system dominated by meteoric water generated greisen in the granitoid rocks and produced the vein system in the roof-zone of the stock. They moreover argued that this event was probably initiated and driven by burial of the district beneath a sedimentary basin.

Recently, Kerrich and Beckinsale (1988) have advanced an different model for Mae Lama er lithophile metal districts in western Thailand, without pointing out the extent to which ier model has been abandoned. On the basis of oxygen isotope analyses, they conclude ny of the granitic bodies in the region have interacted with meteoric waters. They also the discordance between Rb - Sr and K - Ar dates for intrusive rocks of this region to a of fluid/rock interaction. However, these authors now appear to accept the genetic ship between the Sn - W mineraliztion and S-type granitoid magmas. Thus, the late-stage n of groundwater was not apparently responsible for Sn - W concentration.

^{40}Ar/^{39}Ar Age Data

;amples of granitoid and mineralized rocks (Fig.1) from the Mae Lama - Tae Song Yang area were dated by Charusiri (1989) using ^{40}Ar / ^{39}Ar step - heating and total - fusion ues at Queen's geochron laboratory.

ı the *Mae Lama* district, a concentrate inferred to comprise both magmatic and hydrothermal ites (Charusiri, 1989), from a muscovite (± biotite) granite (MLM-9), and hydrothermal ite from a W- quartz vein (MLM-O) display age spectra which record well-defined plateau ca. 69.5 and 70.6 Ma, respectively. Muscovite concentrates from the younger scheelite) and sphalerite-bearing (MLM-14) veins gave identical total-fusion date of ca. 69.2 and ı, respectively. Another muscovite concentrate, from a leucogranite gave a total-fusion ;7.7 Ma.

n alkali feldspar (microline) from the granite (MLM-9) has been dated using the step- technique. The age spectrum displays an internally-discordant profile, clearly reflecting al distrubance. As discussed by Zeitler and Fitz Gerald (1986), the maximum ages d at low-and high-temperatures steps for alkali feldspar ae geologically meaningless, lated solely to the incorporation of excess ^{40}Ar. The only minor turbidity of the dated alkali (Charusiri, 1989) implies that Ar-loss was not caused by fluid-rock interaction during the oling of the pluton (see Parsons et al., 1988). We interpreted that the Ar-loss from feldspar ı volume diffusion (Turner, 1968) and resulted from tectonic effects by the north -trending ıg Son faulting which caused the losses of coherency between perthite lamellae and the eldspar, thereby procucing defects (Charusiri, 1989). The Ar-loss age spectrum of the na feldspar suggests an event of short duration (< 1 Ma), and at low temperatures (150 ;) at 23 Ma.

biotite concentrate from the same granitoid sample yielded a total-fusion age of 58.3 Ma. te age probably records the (tectono) thermal resetting event (proposed above), which ·d to have been insufficiently hot and protracted to reset completely the biotite age.

the *Huai Luang* mine, a muscovite from a Sn-bearing quartz vein (HL-3) yields an age ı with an integrated age of 66 Ma. About 87% of the Ar released defines a rough plateau a. 68 Ma. Muscovite concentrates from a Sn pegmatite (HL-5) and muscovite granitoid gave similar total-fusion ages of 69.5 and 66.3 Ma, respectively.

the *Mae Surie* mine a hydrothermal muscovite concentrate from a W- quartz vein (TSY- een dated using total-fusion and step-heating methods. The total-fusion age is ca. 45.2 muscovite displays an age spectrum with a well-defined plateau, defing and age of 46 minimum at the first step, 21.5 Ma, may be a result of (tectono) thermal resetting such ·rred for the Mae Lama alkali feldspar.

DISCUSSION AND SUMMARY

The new geochronological data suggest a new model for the temporal evolution of tin-tungsten mineralization associated with the granitoids of the Mae Lama mining district. This model is totally different from those proposed earlier by Beckingsale et al. (1979) and Kerich and Beckinsale (1988). The Mae Lama graintoid rocks and mineralization are, herein, interpreted to have been contemporaneous, both occurred at ca. 70 Ma and were overprinted by a Mae Hong Song faulting at ca. 23 Ma. The $^{40}Ar/^{39}Ar$ age data, together with the geologica evidence and considerations regarding ore-genesis, lead the authors to reject the 130 Ma Rb - Sr whole-rock isochron of Beckinsale et al. (1979).

The authors also finds unconvincing Beckinsale et al.'s (op. cit.) model ascribign the ore deposits to water/rock interaction in hydrothermal circulation systems driven by deep burial beneath a thick pile of sediments in an area of high heat-flow. If the fluids responsible for mineralization were generated in this manner, they should have composition charcteristic of basinal brines : i.e., a high salinity and enrichment in Ca and K as well as Na (Roedder, 1984). The authors's fluid inclusion data indicate that the early wolframite-depositing fluids were, instead, of rather low salinity, such as would be in permissive agreement with equilibration with a granitoid magma (Kilinc and Burnnham, 1972).

The whole-rocks Rb - Sr dating of granitoids is, a questionable procedure (Roddick and compston, 1977; Liew and Page, 1985). A consensus is evolving that such data are unreliable indicators of the age of granitoids, particularly those of S-type origin, even when they are "analytically acceptable". It is inferred that the degree of isotopic exchange required to homogenize strontium isotopes is considerably higher than the effective rate of diffusion in the melt (Parrish and Roddicck, 1985).

An attempt was made to reassess the Rb - Sr whole - rock data for all types of granites in the Mae Lama district. A new "isochron" was prepared (Fig. 2), integrating the data of Beckinsale et al. (1979) and von Braun et al. (1976). The "age" obtained is approximately 77 Ma and the initial Sr ratio is about 0.7181. Because the isochron comprises two clusters of points, and there is scatters about the "best - fit" line, the resulting Rb - Sr age is considered unreliable, although it is only slightly older than the $^{40}Ar/^{39}Ar$ dated. However high initial Sr ratio indicates that the granitoid, in fact, is of S-type origin.

From the standpoint of thermal evolution, the primary fluid inclusion data show that the hydrothermal muscovites crystallized at ca. 300 - 425°C, close to the Ar - retention tempereture of this mineral, and under low confining pressures (2 kbar). Thus, it is considered unlikely that the micas could have experienced long, ca. 60 Ma, cooling history prior to argon retention. Together with the geological evidence for a transition from magmatic, through pegmatitic, to hydrothermal conditions, these observations are interpreted by the authors to indicate that granite emplacement and the successive stages of mineralization took place within a brief interval in the latest-Cretaceous. Meteoric waters may have been involved in ore formation (Kerrich and Beckinsale, 1988), but the ultlimately magmatogene character of the mineralzation is difficult to dispute (Charusiri, 1989). The north-trending Mae Hong Son faulting may have occurred during the earliest Miocene, possibly at temperature of about 210-220°C.

The authors also conclude that the Middle Eocene (ca. 46 Ma) dates record the age of Tae Song Yang leucogranite intrusion and Mae Surie Sn (W-) mineralization. The date may also

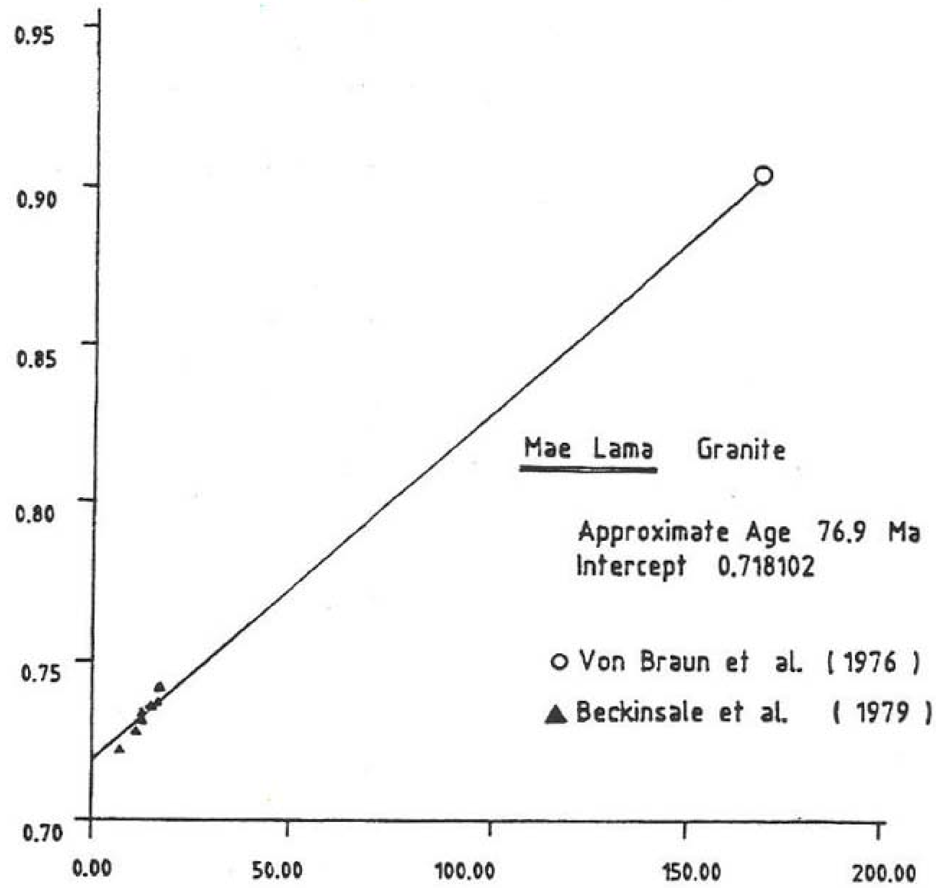

Figure 2. A Rb - Sr "isochron" diagram incorporates the published whole - rock analyses of the granitoid rocks from the Mae Lama District, Changwat Mae Hongson, Data from von Braun et al. (1976) and Beckinsale et al. (1979).

indicate that the regional Mae Ping fault-zone may have been active at this time, controlling or influencing the location of the mineralized granitoid bodies.

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