Granite belts in Thailand: evidence from the 40Ar/39Ar geochronological and geological syntheses

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Abstract—40Ar/39Ar radiometric age-dating results together with petrochemical studies of granitoid rocks from nearly all parts of Thailand strongly indicate that the granitoid belts (i.e. Eastern, Central and Western) form in different geological and geotectonic environments and show marked contrast in geochronological evolution. The new 40Ar/39Ar dating results differ markedly from those previously reported by other methods. The Eastern Granite Belt formed in Early to Late Triassic (245-210 Ma), the Central Belt in Late Triassic (220-180 Ma) to Middle Jurassic, and the Western Belt in Late Cretaceous to Middle Tertiary (80-30 Ma). Granitoid rocks of the S-type which are considered to be related to Sn-W-REE mineralization are widely present in the Western and Central belts as a result of Shan-Thai/Indo-China and Shan-Thai/Western Burma microcontinental plate collisions, respectively. On the other hand, I-type granitoid rocks are inferred to be related to Cu-Fe-Au-Sb mineralization and are largely limited to the Eastern belt, formed as a result of subduction of oceanic lithospheric plates beneath the Shan-Thai and Indo-China microcontinents.

INTRODUCTION

Granitoid rocks forming long, sinuous belts are widely distributed throughout Thailand (Fig. 1) except for the northeastern part of the country (Khorat Plateau). It is evident that metallic and non-metallic ores, especially those of hydrothermal origin, including tin, tungsten, copper, iron, columbite-tantalite, feldspar, fluorspar, lithium-bearing minerals, and rare earth-bearing minerals (monazite and xenotime) are closely related to some types of granite in both space and time. A better understanding of the evolution and distribution of granites would be of benefit to mineral exploration in Thailand.

This study aims to present the ages and age ranges of granite belts in Thailand using the 40Ar/39Ar geochronological technique (McDougall and Harrison, 1987) which is for the first time introduced to Thailand and Southeast Asia. The study also indicates some contrasting ages of granitoid rocks in comparison with those of other dating methods. Rock samples have been collected from 17 areas (Fig. 2), from major currently operating Sn and W mines and from several granitoid stocks and batholiths. The areas under investigation have been selected in order to represent the best target areas for this study. A total of 106 samples of rocks and minerals have been radiometrically analyzed and dated at the Geochron Lab, Queen's University, Ontario, Canada. The results provide not only accurate ages of mineralization (Charusiri, 1989) but also the ages and history of granitoids and granite belts in Thailand (this paper). Details of the analytical procedures for the 40Ar/39Ar geochronological method of analysis can be found in Charusiri (1989) and Charusiri et al. (1989).

Granite–mineral deposits: research concepts

Granitoid rocks in Thailand are part of a sinuous batholithic belt (2500 km long, 600 km wide) extending throughout the Southeast Asian region. It is well documented that this granite belt is one of the most important and largest sources of metallic mineral deposits in the world (Charusiri, 1989). The exploited tin from this region comprise three-quarters of the total world tin production (Nakapadungrat, 1982). From 1983 till the present, 40% of primary tin has been recovered in this region.

These granites trend in an approximate north–south direction with slight curves. This trend commences from Yunnan province, southern China and extends to Shan province, northern Myanmar and northwest of Laos through the whole of northern Thailand and covers the whole of the Thai–Malay peninsula. It ends at Sumatra Island, western Indonesia. The granite of the so-called “Tin Belt” is a southeastern part of the Alpine–Himalayan mountain range.

This granite belt has been the focus of interest and geological research especially on tin and tungsten for decades. Due to the decline in world market price of the two metals at present, many tin and tungsten mines have shut down. Lately, studies on pegmatite relating to columbite–tantalite (Suwimonpreecha, 1989) and uranium–thorium-bearing minerals (Wilson and Akersblom, 1982) are emphasized. Geological research has also turned to the study of the relation between granite and rare earth elements (e.g. Khantaprab et al., 1990). It is inferred that rare earth elements genetically coexist with tin and tungsten.

The geological setting of granitoid rocks in Thailand has been studied intensively by several authors (Baum...
Granitoid Belts and Their Ages

Concepts of age, origin and evolution of granitoids in Thailand have been revised herein according to data obtained from the 40Ar/39Ar dating technique (Charusiri, 1989). Granitoids in Thailand and also in the Southeast Asian region can be subdivided, on the bases of geological environment, lithology, and geochronology (Ishihara et al., 1980; Pongsapich et al., 1983; Charusiri, 1989), into 3 long, narrow and arcuate belts aligned nearly parallel to each other (Fig. 1). They are designated as Eastern-, Western-, and Central-Granitoid Belts. Details of individual belts are as follows.

Eastern Granitoid Belt

This belt extends from Billiton Island, Indonesia, eastern Peninsular Malaysia, eastern Thailand through the edge of Khorat plateau and ends at Laos and southern China (Fig. 2). Generally this granitic belt is emplaced in Upper Paleozoic sedimentary and volcanioclastic sequences. Granitic activity was accompanied by volcanism which persisted from Carboniferous to the Late Triassic. The largest body of granitoid rocks is the Tak Batholith in Tak province, northern Thailand which has been systematically studied by Teggin (1975), Pongsapich and Mahawat (1977) and Mahawat (1982). Smaller plutons are located in the areas of Phrae-Nan, Loei, Chantaburi and Narathiwat provinces.

The granitic batholiths of the Eastern Belt frequently display varying zones from “true” granite (following the classification of Streckeisen, 1976) in the central part of the batholith to more mafic-rich granitoid (quartz diorite, granodiorite) at the edges of the batholith. In general, granitoid rocks belonging to this belt comprise mainly quartz and 2 feldspars (alkali- and calcium-rich). Alkali feldspar is dominantly pink orthoclase. Calcium-rich feldspar (plagioclase), oligoclase to andesine is insignificant. Greenish brown to green hornblende and biotite are major mafic minerals and muscovite is rare. Geochemical studies of Eastern-Belt granitoids (Mahawat, 1982 and Charusiri, 1989) indicate that the granitoids originate from differential crystallization or partial melting from true magma. According to the classification of Chappel and White (1974), this granite is of I-type affinity. A large quantity of magnetite is also present in the rocks. The granitoids are called magnetite-series granitoid, following the classification of Ishihara et al. (1980).

Granitoids from 3 type-localities of the Eastern Belt (Fig. 2) have been dated by 40Ar/39Ar technique. It has been found that ages of the granitoids range from 210 to 245 Ma (Fig. 3) and can be grouped into 4 intervals; 210 Ma, 220-225 Ma, 227-235 Ma, and 240-245 Ma. With integration of geological study at Loei province, it has been interpreted that granitoids of the older interval (>240 Ma) is likely to be associated with and related temporally and spatially to gold mineralization whereas granitoids of the younger internal (220-225 Ma) are responsible for iron, copper, lead and...
Granite belts in Thailand

zinc mineralization. The average age of granitoids at Doi Ngom, Phrae province is 235 Ma. A granitic trend from Chantaburi province to the Thai-Cambodia border was dated at approximately 210 Ma, which is younger than that of Tak province (220-225 Ma). However, ages of granitoids at Laos and Malaysia which are inferred to belong to the same granitoid belt (i.e. Eastern Granitoid Belt) are slightly older. Lasser et al. (1972) reported that
Fig. 3. Index map showing distribution of granitoids and the ages of Eastern Granitoid Belt during 220–245 Ma. Numbers in boxes to be multiplied by 10^6 years.

granite and diorite at Sanakarm area, Laos (about 15 km north of Amphoe Chiangkarn, Loei province) which are closely related to copper, lead and zinc mineralizations are of Early Permian (260–270 Ma). In eastern Malaysia, granitoids are as old as 240–290 Ma (Late Carboniferous to Early Triassic; see Khoo and Tan, 1983; Yap, 1986). It is important to note that, except for the Doi Ngom tungsten deposit in Phrae province, there is no tin–tungsten deposit in this granitoid belt. In addition, it has been proved by the 40Ar/39Ar dating method that the age of tungsten–stibnite mineralization at Doi Ngom is about 35 Ma (Mid-Tertiary), which is much younger than granitoid emplacement.

A low initial Sr isotopic ratio (~0.70763) as recalculated by Charusiri et al. (1991) from Bignell's (1972) Rb–Sr data of Chantaburi granitoids and the occurrence of hornblende–sphene assemblage in granitoid series advocate that the granitoids are of I-type affinity. It is also inferred from our geological investigations and paleomagnetic data of Bunopas (1981) that the Shan–Thai microcontinental blocks which lay isolated between the Paleozioc Tethys and the Mesozoic Tethys, were dismembered from their sister micro-

continents (Tibet, Iran, Afghanistan, and Turkey; Bunopas, op. cit.) and were detached from the northern edge of Gondwanaland during Middle Carboniferous to Middle Permian. The Shan–Thai microcontinent with its Paleozoic passive (continental) margins was carried northward rather rapidly and rotated slowly clockwise. The occurrence of large granitic pebbles in Permo-Carboniferous pebbly mudstone (or diamictite) possibly suggest a Hercynian orogenic event during the Carboniferous. The widespread distribution of Shan–Thai Permian limestone reflects a Shan–Thai microcontinent of low relief with entirely passive margins, isolated on the Tethys–Paleoethys boundary (Zonenshayn and Gorodnitskiy, 1977). Towards Late Permian, the Shan–Thai and Indo-China microcontinents were considered to be rapidly approaching a convergent plate margin along the southern edge of South China. Late in the Permian, a spreading ridge developed in the Shan–Thai and Indo-China and a pair of subduction zones was formed, one dipping westward beneath Shan–Thai, and the other dipping eastward beneath Indo-China.

Permo-Triassic volcanic and volcanic-elastic in northern Thailand are interpreted to represent two separate volcanic-arc facies (Bunopas and Vella, 1978) and form two belts about 150 km apart, one in Sukho–Thai and the other in Loei. It is assumed from our geochronological date that a short-lived spreading ridge of pair-Benioff zone appeared in the ocean separating Shan–Thai and Indo-China late in the Permian and subduction commenced simultaneously along the Shan–Thai and Indo-China margin.

The generation of granitoid rocks in the Sukho–Thai fold belt along the eastern margin of the Shan–Thai block is supported by the widespread occurrence of isolated I-type, metaluminous Triassic (235–220 Ma) granitoid series (Charusiri, 1989) of Tak, Lampang (SE), Phrae, and Nan Provinces. The generation of other granitoid rocks in the Loei fold belt along the western margin of the Indo-China block is evidenced by the voluminous occurrence of I-type, metaluminous Triassic–Early Jurassic (195–243 Ma) granitoid series (Charusiri op. cit.) of Loei, Saraburi and Chantaburi provinces which presumably occurred contemporaneously as those granitoids of the Sukho-Thai fold belt. The tectonics of the magmatic arc of the two fold belts is considered to be of Andean and/or Pacific type along the continental margin (Pitcher, 1987). Cu, Fe, Au, Sb and Mn mineralization are considered to be an end stage of these voluminous more differentiated I-type granitoid series.

Central Granitoid Belt

Except for western and northeastern Thailand, the Central Granitoid Belt covers most of Thailand. The belt comprises a series of plutons underlying almost all of northern-central Thailand, peninsular Thailand, the main range of Malaysia and the Bangka, Singkep and Tuju Islands of Indonesia (Fig. 5). Within Thailand, this granitoid belt encloses the areas of Chiangrai,
Granite belts in Thailand

LATE PERMIAN - EARLY TRIASSIC (220-245 Ma)

Fig. 4. Plate tectonic reconstruction for the generation of 220-245 Ma, I-type granitoids of the Eastern Granitoid Belt by subduction of the oceanic crust beneath both the Shan-Thai and Indo-China blocks.

Chiangmai, Lampang, Lumphun in the north; Chonburi, Rayong in the east; and Suratthani, Nakorn Srimhammarat, Songkla, Yala in the south. In comparison, the granitoids of the Central Granitic Belt is quite different from those of the Eastern Belt in both origin and geological environment. The country rocks intruded by the Central Belt granitoids are mainly Late Paleozoic to Early Mesozoic elastic sedimentary rocks without any associated voluminous volcanic or volcano-sedimentary rocks.

More than 90% of granitoid rocks in this belt are largely confined to granite sensu stricto, following the classification of Streckeisen (1976). The belt is considered to be characterized by mesozonal, porphyritic, coarse-grained, biotite-rich plutons (Liew and Page, 1985; Hutchison, 1983; Cobbing et al., 1986; Charusiri, 1989). Mafic minerals such as green hornblende are not common. Muscovite is normally found and increasingly present in the area adjacent to tin–tungsten deposits. Quartz is found in equal amounts to feldspar. Long laths of megacrystic feldspar are frequently microcline and microcline-perthite. Geochemistry of granitoids in this belt verifies that they originated from the partial melting of pre-existing crustal rocks. According to the classification of Chappel and White (1974), the granitoids are of S-type affinity. In other category, when ilmenite in these granitoids are taken into consideration, the granitoids are classified as ilmenite-series granitoids (Ishihara, 1977). However, geological surveys and geochemical analyses indicate that I-type granitoids and magnetite-series granitoid, are also found in the belt. The existence of I-type granite has not been reported (see Charusiri et al., op. cit.). Large areas of I-type granitoids are recently discovered in Doi Mok, Chiang Rai (Charusiri, 1989) and Doi Tung, Chiang Rai.

Foliated granitoid intrusions which are associated with greissic and other high-grade metamorphic rocks in the Central Belt have been assigned a Precambrian age by several workers (Dheeradilok, 1973; Campbell, 1973; Workman, 1975; Bunopas, 1981; Pongsapich et al., 1983). The exact age of these deformed intrusive rocks remains enigmatic in the absence of geochronological data.

Three subparallel north–south chains of crystalline rocks may be defined in the Central Granite Belt, particularly in northern Thailand: a series of granitic rocks in the crystalline basement complexes just west of Chiang Mai and Tak provinces is flanked by arrays of granitoid plutons (see Fig. 5). Cobbing et al. (1986) inferred the granitoids in the central crystalline complexes to represent a migmatitic zone of Permo-Triassic anatexis. The granitoid rocks of this domain (Cobbing et al., op. cit.) are generally coarse-grained, but are extremely variable in texture, ranging from abundantly megacrystic to equigranular and in mineralogy, from biotite-rich to biotite–muscovite-bearing. All of the rocks are intensely deformed, some having a well-defined cataclastic texture. Mostly they display a well-defined subhorizontal foliation, such that the primary magmatic textures are rarely observed.

The eastern granitoid chain of the Central Belt comprises the Mae Chan pluton of Changwat Chiang Rai, colinear north–south strings of the Fang-Mae Suai and the Wiang Pa Pao-Khuntan batholiths (Fig. 5). The western chain, located near the Thai–Burmese border south of Changwat Mae Hon Son consists largely of composite plutons (the Mae Sariang complex: Braun, 1976), extending from Amphoe Pai, Changwat Mae Hong Son, through Amphoe Samoeng, Changwat Chiang Mai, to the western part of Changwat Tak.
The granitoids of the Central Belt are emplaced into Paleozoic metasediments and interred Precambrian rocks. Contacts with the former are relatively sharp and thermal aureoles are narrow. The plutons appear to cross-cut the central migmatite zone (Cobbing et al., 1986) but some contacts are transitional. The granitoid rocks are mainly undeformed, but foliation is present in discrete zones.

In southern Thailand, the granitoid plutons of the Central Belt include those exposed in Surat Thani, Songkhla, and Yala provinces (Fig. 7.1). The rocks are generally similar to those in the north. They are commonly biotite-bearing coarse-grained and porphyritic, grading into equigranular and medium-grained facies in some plutons.

$^{40}$Ar/$^{39}$Ar dating (Charusiri, 1989) estimates the age of the Central Granitoid Belt as 180-220 Ma (Fig. 4). This period is further subdivided into 2 intervals; 200-220 Ma for northern Thailand, and 180-200 Ma for southern Thailand. The ages of mineralization of major tin–tungsten deposits such as Doi Mok, Chiangrai province, Tung Luang, Lampang province; Tung Po-Tung Kamin, Songkla province; and Pinyok, Yala province, etc., are mainly in the same period as those of granites in the Central Belt. However, some known tin–tungsten deposits which carry rare earth elements (Khantaprab et al., 1990) such as Samoeng, Chiangmai province, and Khao Kamoii, Supanburi province have been proven to be 56 Ma (Tertiary) whereas the main phase granitoids in those areas were previously stated to be of 220–240 Ma (Teggin, 1975; Nakapadungrat et al., 1984). Charusiri et al. (1991) concluded from their recalculation of Rb-Sr whole-rock data that most of the granitoids of the Central Belts are of S-type affinity on the basis of high initial Sr isotopic constraints.

Geotectonically, the gradual change from Early and Middle Triassic marine facies of Lampang Group to Late Triassic freshwater fluviolacustrine facies forming at the base of the red-bed Khurat Group is considered to represent the final closure of the Paleotethys seaway that had previously separated Shan–Thai from Indo-China. During the Early Triassic, Shan–Thai probably first contacted Indo-China at its southern end and rapidly swung clockwise to unite with the whole of western Indo-China (Bunopas, 1981). The Shan–Thai and Indo-China continental collisions resulting from the closure caused folding of continental margin deposits and widespread granitoid intrusion known as the Indo-Asian Orogeny (or Cimmerian Orogeny). Amalgamation of these two continental blocks may have occurred in the Permo-Triassic (Hutchison, 1983; Bunopas and Vella, 1983) or possibly earlier (Helmke and Lindenberg, 1983; Helmke, 1985). Our $^{40}$Ar/$^{39}$Ar data (210–180 Ma) of the granitoids of the Central Belt indicate that collision of these two microcontinents might have taken place during Permo-Triassic rather than earlier. This suture zone or the so-called Nan River ophiolite suture zone (Barr and Macdonald, 1987) extends from the Sunda Shelf south of Billiton Island through the Bentong–Raub belt in Malaysia (Hutchison, 1975) to the Sakaew ophiolite zone in eastern Thailand and the Nan–Uttraladit suture belt in northern Thailand (Bunopas, 1981). The granitoids with high initial Sr ratios (or S-type granites of the Central Belt) originated as a result of partial melting of thick continental crust. The crustal thickening may have been directly related to the Shan–Thai and Indo-China collision. These created voluminous S-type granitoid occurring as N–S trending mountain chain (Fig. 5). Emplacement of granitoid magma and accompanied rhyolite at high levels in the crust is assumed to have taken place in a tensional or non-compressional tectonic regime. Therefore, when collision-related granites were generated late in the Triassic, the collision was already completed. The accompanying compressional stresses had ceased and the resultant relaxation of horizontal stresses allowed vertical stresses to be relieved by isostatic adjustment. It is also believed that the westward-dipping subduction beneath Shan–Thai continued longer than the eastward-dipping subduction beneath Indo-China and that consequently the margin of Shan–Thai overthrust the margin of Indo-China, causing the so-called A-subduction zone (Fig. 6). This subduction is inferred to have triggered the generation of minor amounts of I-type
LATE TRIASSIC – EARLY JURASSIC (220-179 Ma) (Post Collision)

SHAN-THAI

KHORAT GROUP

RHYOLITE

RHYOLITE

MOLASSE

GRANITE INTRUSIONS

INDOCHINA

Fig. 6. Plate tectonic reconstruction for the generation of 179-220 Ma, S (+ I) granitoids of the Central Granitoid Belt by continental collision between Shan-Thai and Indo-China blocks.

Granitoids in the Central Belt or these granitoids may have occurred as a result of relaxation of the crust following collision. It is also postulated that the westward-dipping subduction zone beneath Shan-Thai ceased sometime in the Late Triassic. The red beds of the Khorat Group may have been deposited on the subsiding, partly overthrust margin of the Indo-China continent (Fig. 6).

Western Granitoid Belt

The Western Granitoid Belt, similarly, orientates in the north-south direction and parallel to the aforementioned belts. Granitoid rocks are distributed dominantly in Myanmar, especially in the east of the country (Fig. 7). Clarke and Beddoe-Stephens (1987) assigned a Cretaceous Sn-W-associated granite in northern Sumatra to the Western Granitoid Belt. Granitoids of the Western Granitoid Belt cover a much smaller area in Thailand than those of the other belts and occur as a narrow strip in western Thailand and along the Thai-Myanmar border, (Fig. 6). The belt includes the small, elongate, isolated granitoid stocks of the Mae Lama-Tae Song Yang mining district, strings of plutons in Kan-chanaburi province (the Pilok district), and Prachaub Khirikhan, and numerous plutons in Ranong, Phang Nga and Phuket provinces. The country rocks within this granitoid belt are mainly Permian to Carboniferous clastic sedimentary rocks with no evidence of contemporaneous volcanism, similar to that of the Central Granitic Belt.

Geological, petrological and mineralogical studies on granitoids reflect true granite (Streckeisen, 1976) which, again, are similar to those of Central Granitoid Belt. Hornblende is relatively rare whereas brown biotite and muscovite are very common, as well as quartz and microcline. Geochemically, about 98% of the granitoid rocks in this belt are of S-type and ilmenite-series. Small areas of unexpected I-type and/or magnetite-series granitoids are present locally, e.g. those in Phuket and Phang Nga areas (Charusiri, 1989) and in Amphoe Muang Prachaub Khirikhan.

Age determination using ⁴⁰Ar/³⁹Ar method on the granitoids from this belt reveals that both I-type and S-type granitoids in the Western Belt are 50-88 Ma (Late Cretaceous to Early Tertiary). These ages of granitoid emplacement can be further subdivided into 2 periods, 65-88 Ma (Fig. 8) and 50-60 Ma (Fig. 9). Distribution of these two granitoid of these two periods are illustrated in Figs 8 and 9. Associated tin and tungsten deposits together with rare earth elements are inferred to have been related temporally and spatially with S-type granitoid of both periods. In addition, 45 Ma S-type granitoids also occur, but in smaller amounts, and are related to tin- and tungsten-mineralization in northern and southern Thailand. These granites were reported by Nakapadungrat et al. (1984) to have 130-90 Ma age using the Rb–Sr whole-rock method.

With reference to geotectonic investigations, the widespread occurrence of Cretaceous-Tertiary granitoids with high initial isotopic Sr ratios are inferred herein to have been formed by the partial melting of the pre-existing rocks within the crust. This feature is directly related to the collisions of the Shan-Thai, the Western Burma and the Indo-Burma blocks (Fig. 8). The ⁴⁰Ar/³⁹Ar geochronological data (88-50 Ma) of the granitoids rocks of the Western Belt strongly suggest that the collision of these two continents might have been originated during Campanian, which agrees with the conclusion made by Mitchell (1977). The area referred to
Late Cretaceous. The Western Burma oceanic and Shan–Thai continental collision resulted in the formation of first stage, S-type, mineralized, peraluminous granitic plutons (88–65 Ma) of the Western Belt and of the Late Cretaceous-Tertiary fore-arc basin succession of Mogok Belt (Mitchell, 1981, 1985). The occurrence of a jadeite-albite dyke and glaucophane schist (Soe Win, 1968) was possibly related to this collision. The compression caused by the Indo-Burman and Western Burma blocks during the Paleocene-Eocene may have caused the generation of the younger suite of anatectic, S-type, peraluminous and mineralized granitoids (60–55 Ma) in the Western Belt. The generation of olistostromes and west-directed thrusting can be best explained by the second collision (Mitchell, 1985). However, the age of collision (Campanian) proposed by Mitchell (op. cit.) is older than that proposed in this paper.

CONCLUSION

From this study, it is evident that granitoids in Thailand can be divided into 3 belts; Western, Eastern,
Granite belts in Thailand

LATE - CRETACEOUS - MIDDLE EOCENE (88 - 45 Ma)

Fig. 9. Plate tectonic reconstruction for the generation of 88-50 Ma, S (+I) type granitoids of the Western Granite Belt by continental collision, between Shan-Thai and Western Burma and between Western Burma and Indo-Burma blocks.

Age-dating results on granitoids obtained from the 40Ar/39Ar technique is different from those by Rb-Sr (whole-rock analysis) and K-Ar methods. It can be concluded that ages of the Eastern Belt granitoids in Thailand, which has been reported to be as old as Permian, is restricted to Triassic. Central Belt granitoids, previously recorded as Triassic, have been postulated in this study to have taken place during Late Triassic to Middle Jurassic. For the Western Belt, the ages of the granitoids are Late Cretaceous to Middle Triassic which are younger than those proposed by previous studies.

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