

The magnetite-series and ilmenite-series granitoids and their bearing on tin mineralization, particularly of the Malay Peninsula region

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Abstract: About 140 granitoids were studied magnetically and microscopically in the southern half of the Malay Peninsula (ca. N2°–N10°). The late Paleozoic to early Mesozoic granitoids of the Main Range of belt Malaysia and its northern extension to southern Thailand, and also the Eastern belt of Malaysia, are mainly composed of the ilmenite-series (91%). But small plutons of the Central intrusive belt and Cretaceous granitoids are of the magnetite-series in general. Tin deposits are distributed in the ilmenite-series granitic terranes. Thus genetic relationship between the reduced species granitic magma and tin mineralization is suggested.

INTRODUCTION

The significance of opaque oxides of granitoids for tin mineralization was first pointed out by ARANYAKANON (1961, p. 101), who noted that granitoids accompanying tin deposits have little magnetite, less than 0.02 wt. %, but "tin-barren granitoids" contain an average of 1.26 wt. % of magnetite. A similar conclusion was obtained independently from studies of granitoids of W–Sn and Mo metallogenic provinces in Southwest Japan (ISHIHARA, 1971), and the genetic bearing of magnetite in granitoids was discussed in terms of oxygen fugacity of the granitic magmas (ISHIHARA and TERASHIMA, 1977; ISHIHARA, 1978).

Tin can have either tetravalent or divalent state in magmas (HAMAGUCHI et al., 1964). In the magnetite-series magma, tin can be tetravalent and is consumed in common rock-forming minerals, such as sphene, magnetite, ilmenite, epidote-group minerals and hornblende, in the early crystallization stage of the magmatic differentiation. Thus this type of magma cannot have a large concentration of tin in the residual liquid.

In the ilmenite-series magma, on the other hand, tin may be in the divalent state and has no suitable substitution site in the rock-forming minerals. Thus tin can be accumulated in the residual liquid. If the original magma is high in tin and transport media (e.g., F and Cl), tin deposits can be formed in an apical part of the granitic magma. It was therefore considered that the presence of the ilmenite-series granitoids is a prerequisite in major tin fields.

The above interpretation was tested in southern Thailand and some other parts of the Malay peninsula region. This paper describes results of the reconnaissance study. The magnetite-series and ilmenite-series granitoids can be identified easily in the field by magnetic susceptibility meter, assemblage of ferro-magnesian silicates, color of biotite and other methods (see ISHIHARA, 1977). Here, the Kappameter

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UGF-KT3 was used and the magnetic susceptibility was measured with the distant stick. This device gives magnetic susceptibility in the SI unit, which can be easily converted to the CGS unit of KANAYA and ISHIHARA (1973). SI unit of 40×10^{-3} , which was obtained by comparison between this value and mineralogical studies on the Japanese granitoids, is taken as the boundary separating the two series.

GRANITOIDS IN SOUTHERN THAILAND

Granitoids of southern Thailand occur as independent plutons. Their ages are mostly Carbo-Jurassic (ISHIHARA et al., in prep.) but some may be Cretaceous, especially around the Phuket-Phangnga-Krabi area (GARSON et al., 1975). The granitoids consist largely of porphyritic biotite granite containing potassium feldspar megacryst. Muscovite-biotite granite, which often contains tourmaline, is present in small

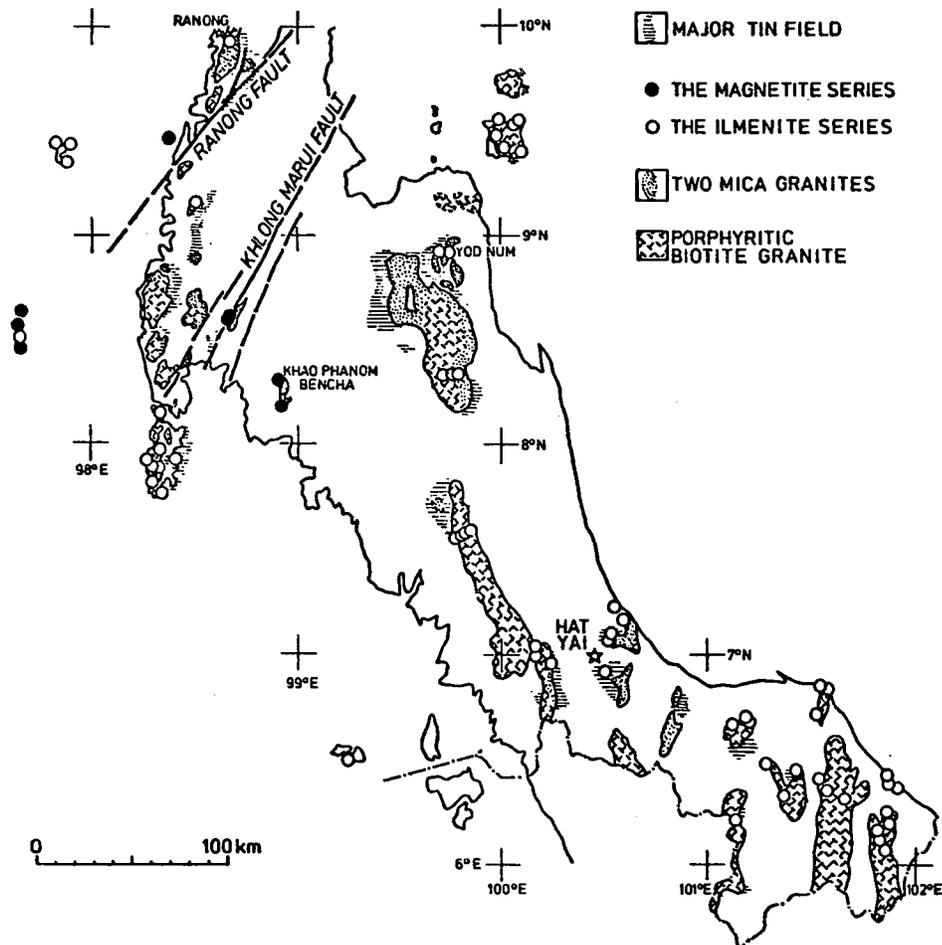


Fig. 1. Distribution of the magnetite-series and ilmenite-series granitoids and tin deposits in southern Thailand. General information was taken from JAVANAPHET (1969), ANGKATAVANICH (1975) and GARSON et al. (1975). Eleven localities of the magnetite-series and ilmenite-series were obtained from RASRIKRIENGKRAI (1976) and GARSON et al. (1975).

stocks and apical parts of large plutons. The porphyritic rocks have generally the feldspar ratio of monzogranite (or adamellite), whereas the two mica rocks are syenogranite (or granite) in general. Figure 1 illustrates the distribution of these two types.

Foliation is rather distinct throughout these plutons, which is shown generally by parallel arrangement of the megacryst. So-called stressed granite occur in a limited extent in narrow zones at several localities. Potassium feldspars are white in color in most plutons, but are pink in the Yod Nam stock. These general characters are similar to those described by HUTCHISON (1977) in the Main Range granites of Malaysia. Biotite is black with reddish tint, which is characteristic of that of the ilmenite-series granitoids. This observation is consistent with their low values on magnetic susceptibility. Nearly all the studied granites give the SI unit below 30×10^{-3} .

The lineated granite of GARSON et al. (1975) occurring between the Khlong Marui and Bang Kram faults yields the SI values from 110 to 270×10^{-3} , which are equivalent to 0.13 to 0.32 vol. % of magnetite, respectively. This granite belongs to the magnetite-series. Euhedral to subhedral magnetites occur as independent grains or aggregates under the ore-microscope and have been martitized, which may indicate a shallow level of formation of this pluton.

GARSON et al. (1975, p. 32) noted occurrence of sphene and titanomagnetite in granitoids at Khao Phanom Bencha in the Krabi district. Primary sphene is a characteristic mineral of the magnetite-series granitoids (ISHIHARA, 1977). Their high Fe_2O_3/FeO ratio of bulk chemistry (GARSON et al., 1975, Table 2) also indicates that this pluton belongs to the magnetite-series.

TABLE 1
THE MAGNETITE-SERIES AND ILMENITE-SERIES GRANITOIDS OF THE
MALAY PENINSULA REGION BY NUMBER OF MEASUREMENT
EXCLUDING THOSE DETERMINED BY BULK CHEMICAL ANALYSES

Area and age (number of analysis)	Magnetite-series	Ilmenite-series	Tin mineralization
Southern Thailand			
Northwest of Krabi district, Cretaceous (n=22)	8	14	Intense
Main part, Carbo-Jurassic (n=48)	0	48	Moderate
Whole area (n=70)	8(11%)	62(89%)	
Peninsular Malaysia			
Southern part, Cretaceous (n=12)	11	1	None
Central belt, Permo-Triassic (n=9)	9	0	Rare
Eastern belt, Permo-Triassic (n=28)	6	22	Moderate
Main Range belt, Permo-Triassic (n=45)	4	41	Intense
Eastern and Main Range belts	10(14%)	63(86%)	

On the western off-shore granites between Ranong and Phuket areas, RASRIKRIENGRKAI (1976) reported modal analyses that contain more than 0.2 vol. % of magnetite or opaque oxide minerals in some areas. The magnetite-series and ilmenite-series granitoids can be separated by 0.1 vol. % of opaque oxide minerals, except for unusual ilmenite-series ones that contain a large amount of pyrrhotite (ISHIHARA, 1977). Four samples from the western off-shore area seem to belong to the magnetite-series. Granites in the Haad Som Pan deposit area of Ranong province (ARANYAKANON, 1961) might be composed of the ilmenite-series.

It appears that the granitoids in southern Thailand consist largely of the ilmenite-series (Table 1). The magnetite-series granitoids tend to occur sporadically in and near the Khlong Marui and Ranong fault zones. Cretaceous-Tertiary radiometric ages are known in this area, and most are considered to be the result of tectonic, rather than plutonic, rejuvenation of possible Carbo-Jurassic granitoids (GARSON et al., 1975). However, their 55 Ma of the Khao Phanom Bencha may be a true age for crystallization of the stock, because it occurs in the outer part of the fault zones. Thus the granitoids of southern Thailand can be divided into the Carbo-Jurassic one of the ilmenite-series and the Cretaceous-Tertiary one of the magnetite-series, although the latter is very small in areal extent.

GRANITOIDS IN PENINSULAR MALAYSIA

The magnetite-series and ilmenite-series granitoids can be identified by $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio of bulk chemistry (Fig. 2). The Japanese granodiorite and monzogranite are separated by the ratio of 0.5 (TSUSUE and ISHIHARA, 1974). If this empirical criterion is applied to the Malaysian granitoids, the following percentages are obtained from the chemical data of alkali granite, granite, granodiorite and tonalite clans of ALEXANDER et al. (1964):

The magnetite-series: 6 analyses (12%)
 The ilmenite-series: 43 analyses (88%)

Thus, the Malaysian granitoids are also composed mainly of the ilmenite-series.

Chemical analyses of the Eastern belt granitoids reported by RAJAH et al. (1977, Table 1) give slightly higher percentage (ca. 25%) of the magnetite-series. Their analyses of Nos. 1, 2, 3, 4, 5(?), 7 and 26 seem to belong to the magnetite-series (Fig. 2).

About ninety granitoids were examined by the magnetic susceptibility meter. The results are illustrated in Figure 3. Among three major intrusive belts of Permo-Triassic age, the Main Range granite belt, Central intrusive belt and Eastern granite belt of HUTCHISON (1977), almost all of the Main Range granites and Eastern belt granites give the SI values below 30×10^{-3} indicating that the ilmenite-series granitoids are predominant in the Peninsular Malaysia. Sporadically distributed magnetite-series ones in these belts are generally weakly magnetic, except for one pluton northwest of Malacca.

The magnetite-series granitoids seem to occur dominantly in the Central intrusive belt, although the number of analyses is small (Fig. 3). JAAFAR BIN AMAHD (1976, p. 67) reported opaque oxide minerals higher than 0.2 vol. % on the Bukit Besar igneous complex, which should belong to the magnetite-series. The Cretaceous plu-

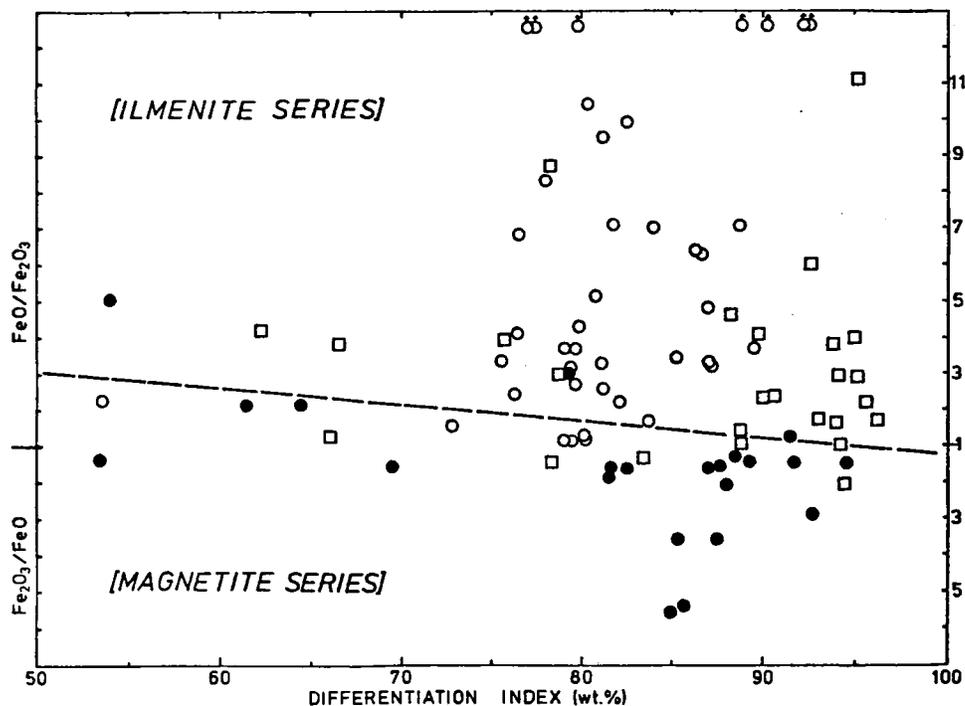


Fig. 2. Ferric/ferrous ratio of selected granitoids in Thailand and Malaysia. Instead of molecular $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio (Tsusue and Ishihara, 1974), weight percentage was simply used to identify the magnetite-series and ilmenite-series granitoids. Broken line separates the two series on the Japanese granitoids, i.e., $\text{FeO}/\text{Fe}_2\text{O}_3$ is roughly 1 to 2 on granite composition ($\text{DI}=95-80$), and $\text{FeO}/\text{Fe}_2\text{O}_3$ is 2 to 3 on granodiorite ($\text{DI}=80-60$) and tonalite and quartz diorite. Open square, Eastern belt granitoids of RAJAH et al. (1977); open circle, Khuntan granite of SUENSILPONG et al. (1977); solid circle, Tak granite of PONGSAPICH and MAHAWAT (1977).

tons, such as Mount Ophir, Gunung Pulai and Pulau Tioman, are also composed of the magnetite-series granitoids (Table 1). Thus abundance of the magnetite-series or ilmenite-series granitoids in the Peninsular Malaysia is different among three geotectonic units of HUTCHISON (1977) and depending upon age of the granitoids.

Magnetite-bearing character of the Central intrusive belt is in harmony with its island arc nature (HUTCHISON, 1977), because typical island arc volcano-plutonic association has magnetite-bearing character (ISHIHARA, 1977). The tendency that magnetite-free rocks predominant in the early Mesozoic terrance but are scarce in the late Mesozoic one is the same as that found in the southern part of Korean Peninsula (ISHIHARA et al, 1978), which is different from the patterns observed in the Japanese island arc environment.

RELATION TO TIN MINERALIZATION

Distribution of tin placer deposits is shown in Figures 1 and 3. The tin deposits seem to be distributed around the ilmenite-series granitoids. The fact that ilmenite is the most predominant heavy mineral in these deposits supports the above conclusion.

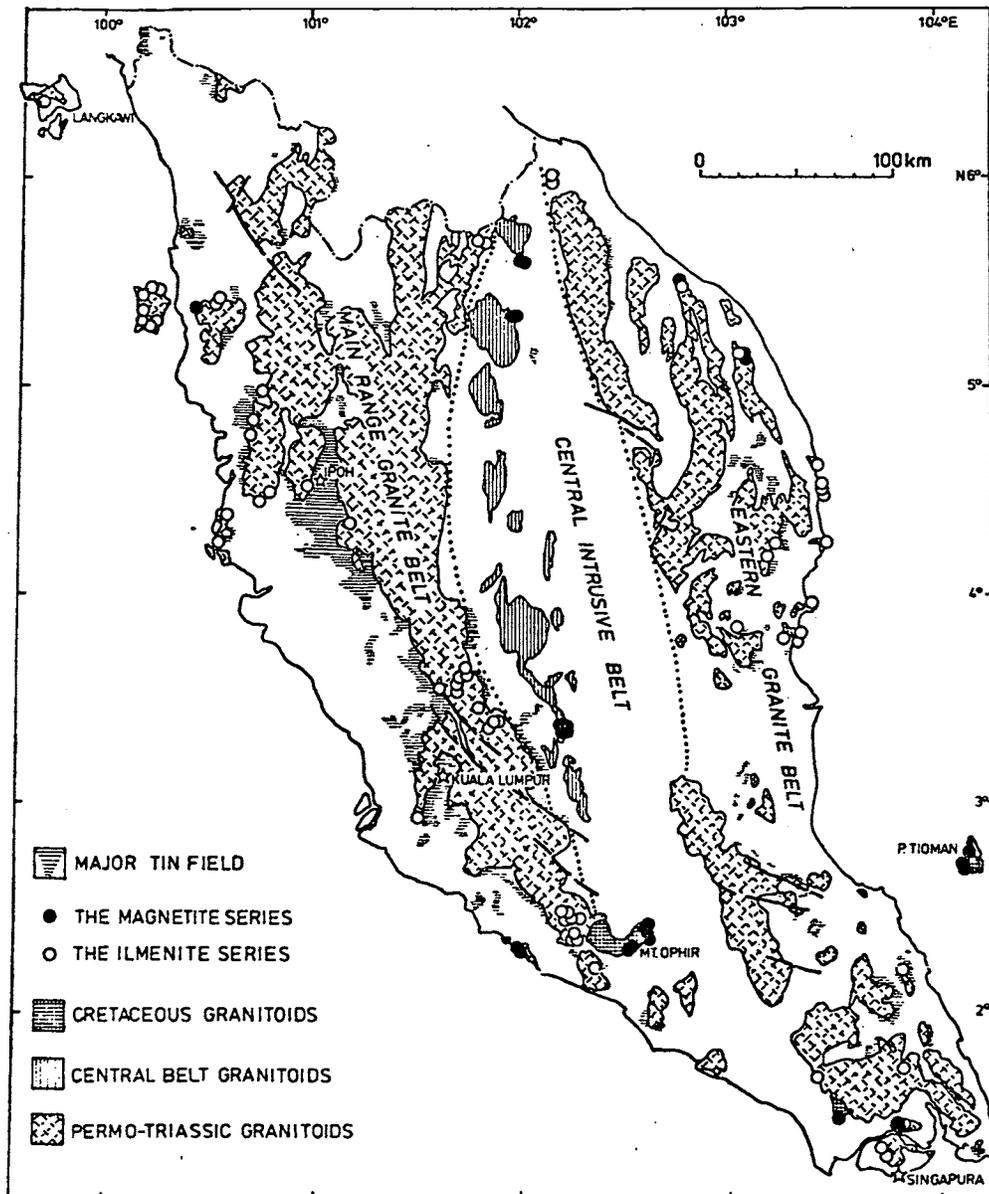


Fig. 3. Distribution of the magnetite-series and ilmenite-series granitoids of the Peninsular Malaysia. General information was taken from YIN and SHU (1973), RAJAH et al. (1976) and HUTCHISON (1977). Six localities of the magnetite-series were obtained from JAAFAR BIN AHMAD (1976).

A large unit of the magnetite-series granite is known as the Tak granite in northern Thailand (ARANYAKANON, 1961). This granite has generally magnetite-bearing character (Fig. 2), and lacks associated tin mineralization (PONGSAPICH and MAHA-WAT, 1977). On the other hand, the Khuntan granite which is mostly composed of the ilmenite-series (Fig. 2) is accompanied by tin mineralization along the eastern margin (SUENSILPONG et al., 1977). Thus it is apparent that the ilmenite-series granites and the tin deposits are related.

Within the ilmenite-series granitic terranes, tin deposits do not occur everywhere. In southern Thailand, coarse-grained biotite granites do not accompany primary tin mineralization, but cassiterite occurs in veins and skarns associated with the finer grained parts of two mica granites, which are present as small stock or at margin of the coarse-grained rocks. These two types of the ilmenite-series granites are chemically distinguished by their Sn and F contents. The primary tin deposits seem to occur around granitic cusps of the ilmenite-series granitic belt, which contained a high content of Sn and F in the original magmas (ISHIHARA et al., 1978).

CONCLUDING REMARKS

This reconnaissance study indicates that the major granitic units of the late Paleozoic to early Mesozoic in southern Thailand and Peninsular Malaysia are mainly composed of the ilmenite-series. Major tin fields are spatially related to the ilmenite-series granitoids. Isolated plutons of the Cretaceous to Paleogene are predominantly of the magnetite-series, which have no connection with tin mineralization.

In the Phuket-Phangnga-Krabi area of southern Thailand, however, Cretaceous to Tertiary granitoids are mostly of the ilmenite-series. The Cretaceous radiometric ages could have been originally the early Mesozoic ones rejuvenated during the Cretaceous period by tectonism and the magnetite-series magmatism. In the above context, it is interesting to know of the magnetite-series/ilmenite-series rock ratio of the Cretaceous granitoids of the Burmese tin belt, i.e., Western belt of MITCHELL (1977).

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