CHAPTER VIII

TIN-BEARING AND TIN-BARREN GRANITES : A DISCUSSION

The studied area is one of the most interesting areas where tin deposits are likely to be temporary and spatially associated with the granites. The only important question remaining to be answered is whether it is true that all the granitic types of Phuket Plutons bear a potential source of economic significance with regard to tin.

Opinion on the topic concerning the differentiation between tin-bearing and-barren granites, however, vary from the optimistic suggesting possibilities of finding tin ores according to the associated granitic types (Chauris, 1965; Hosking, 1967; Groves, 1972; Aranyakanon, 1978; Juniper & Kleeman, 1979) to the pessimistic (Flinter, 1971; Ewers & Scott, 1977) which have questioned such conclusive statement. In many cases, not only several previous authours have found the differentiation but also Rattigan (1964), Klominski and Groves (1970), Hesp (1971), Hesp & Rigby (1974), and Sheraton & Labonne (1979) have attempted to correlate petrochemical and mineralogical composition of granites with tin deposits.

The term "tin-bearing granite" is here taken to mean a granite which has given rise to Sn-mineralization, while a tin-barren granite is one which has not, even though superimposed lode tin deposits may occur within it. When applying the terms "tin-bearing and-barren" to the granites in the area studied, data on Table 4 and Figure 6 indicate that

G-3, G-5, G-4 (including greisen granites) tend to be tin-bearing granites whereas G-1 and G-2 are probably tin-barren ones due to the fact that the former have highly Sn-concentrations in the rocks. Not only the small trace amount of tin in granites can be used to classify such terms, but some criteria based particularly upon the temporal, spatial, mineralogical, and petrochemical aspects are also categorized the tin-related and unrelated-granites.

8.1 Temporal and Spatial Aspects

Tischendorf (1973) studied the relation between granites and associated tin deposits in the 'Erzgerbirge', German Democratic Republic and concluded that there is a close temporal coherence between granites of the Younger Complexes and tin mineralization. Suensilpong (1977a, 1977b) and Mitchell (1979) found similar situation in granites of Thailand and suggested that Late Cretaceous to Tertiary are possible ages of tin mineralization. In areas where there are more than one phase of granites in the plutons, the latest phase seems to be richer in tin than the earlier phases, such as those of Southern Baltic Shield (Sminova, 1974), Central and Eastern Mongolia (Gudsanbun, 1974), Northeast Tasmania (Groves & Taylor, 1973), Eastern USSR (Lugov, 1978), NE Queensland (Sheraton) & Labonne, 1978), Nigeria (Macleod,et al., 1971). In Thailand, many reports on tin-related granites (Aranyakanon, 1961; Pitakpaiwan, 1969, Garson,et al., 1975; Suensiopong, 1977b; Ishihara,et al., 1978; Arrykul, et al., 1978, Beckensale,et al., 1979) concluded and remarked that tin-deposits become dominantly associated with intrusion of granitic magma since an early stage of the post-magmatic stage (greisenization and hydrothermal alteration). The study of granites in the area are temporally in accord with those of the mentioned statements. The biotite-muscovite granites (G-3, G-4 and G-5) are younger than the biotite granites (G-1, G-2). The geochronological data on granites (Table 1) appear to be conformable with the geological observations which suggest that the G-4 granites are the late sequence of major acid intrusions.

Evidence from many countries also suggests that commonly in a given tin field the strongest primary mineralization occurs spatially within, or in the vicinity of clearly defined steep-sided cupolas. Tauson & Kozlov (1973) have emphasized that even within a single pluton, the Sn content can vary considerably from 25 ppm in the apical part to only 5.8 ppm in the abyssal part of the Verkneurmijsky granite massif. MacLeod, et al. (1971) have shown that tin tends to be concentrated in the roof zones of the Nigerian Younger Granites. Similar conclusion had been also reported in tin-bearing granites of Eastern Transbaikal, E. Siberian (Tauson, et al., 1966; Tauson, et al., 1968) and of Blue Tier Batholiths, Australia (Groves & MacCarthy, 1978). In Phuket, in the Pahang Consolidated Mine (Malaysia), and in Cornwall, the strong tin-mineralization is in the vivinity of the marked cuppla (Hosking, 1967, 1971).

In the area of investigation, the more or less biotite-muscovite greisenized granites at Khao Rang, Khao To Sae and Khao Sapam are locally in contact with the sedimentary rocks of Phuket Groups and are believed to be the roof zone. Tin-centents in these granites are found to be much higher than those of the other granites (Table 4b and 6).

8.2 Mineralogical Aspects

The mineralogical characteristics of the granitic rocks that bear more than one sort of mica, muscovite and probably lepidolite, are more important than those granites with only biotite (Tauson, 1968; Tauson, 1974; Wastneck, et al., 1974; Smith in Garson, et al., 1975). In most cases, the hornblende-bearing granites are barren of tin-mineralization (Kloosterman, 1967; Hosking, 1967). Smith (in Garson, et al., 1975) in his summary on the geochemistry of tin-bearing granites pointed out that the role of muscovite seem to be more important than biotite & hornblende. His study also showed that Sn-concentrations in muscovite mineral average about 380 ppm, whereas those found in hornblende and biotite minerals are averagely about 75 and 150 ppm, respectively. Taylor (1979) reported that tourmaline can contain Sn content $>$ any other minerals in granites. Earlier workers (Rattigan, 1964; Bradshaw, 1967; Hesp, 1971; Groves, 1972) indicate that the tin contribution from biotite closely approximates the tin contents of the rocks (both tin-bearing and-barren). They also summarized that biotite is the major concentrator for tin. However, Chauris (1965) has argued against this assumption and showed that tin content of biotites can be higher in the barren granites than in the tin-granites of American Massif (N. France).

Sphene has shown to be a major contributer of tin (Barsukov & Durasova, 1966; Petrova & Legeydo, 1965; Flinter et al., 1972), but primary sphene had been only observed in biotite granites of Phuket Plutons which contain less tin traces than two-mica granites. The present investigation seems to be opposited from those of previous authors.

Particularly noteworthy are the high concentration of volatile components in tin-bearing granites, as suggested by the abundance of fluorite or tourmaline, or both (Tischendorf, 1977; Taylor, 1979). Though not abundant, fluorite and tourmaline are scatterly distributed throughout most of the biotite-muscovite granites and some grains of tourmaline are also found particularly in the G-3 and G-5 granites. These two minerals are also found abundantly in Elizabeth Creek and Esmeralda tin-bearing granites of Australia (Sheraton & Labonne, 1978), Blue-Tier tin-bearing granites (Groves, 1972), and Haad Som Pan granites (Aranyakanon, 1961).

In the USSR, a distinction has been drawn between ilmenite-monazite granites and sphene-allanites, Stemprok (1979) suggested that the ilmenite-monazite granites manifest tin-bearing. Similar conclusion can be made in Phuket Island as reported by Garson, et al. (1975) and Suensilpong & Putthapiban (1979). Studies of the Phuket Plutons also show that biotite granites usually contain sphene and allanite whereas ilmenite and monazite as stated by Garson, et al. (op. cit.) are frequently found as common accessories in biotite-muscovite varieties.

The significance of opaque minerals in granites for tin-mineralization was first pointed out by Aranyakanon (1961; p. 100, 101). He summarized that if the granite has a very small amount of magnetite (0.02 wt% approximately) it may provisionally be regarded as of the tin-bearing granites, but tin-barren granites contain average 1.26 wt% opaque magnetite. Groves (1972) in the study on Blue Tier Batholith reported the magnetite contents of tin-bearing granites being lower than tin-barren ones. A similar conclusion was obtained from studies of Phuket Plutons. G-3, G-4 and G-5 have lower normative magnetite content (average 0.35 wt%) whereas G-1, G-2 have 4 time higher in magnetite contents (average 1.56 wt%) suggesting the former have tendency to become tin-bearing than the biotite.

.Shunso Ishihara (1971, 1977) divided the granites on the basis of the opaque minerals present into a magnetite-bearing magnetite-series and a magnetite-free ilmentite series. Magnetite-series granites are characterized by magnetite (0.1-2.0 Vol.%), ilmenite, hematite, pyrite, sphene and higher ferric/ferrous oxides of bulk chemistry, whereas ilmenite-series granites are characterized by ilmenite (less than 0.1 Vol%), pyrrhotite, graphite, muscovite, lower ferric/ferrous oxides (Tsuesue & Ishihara, 1974). Their studies on Japanese granites and related rocks gave the conclusion that Fe_2O_3/FeO ratios of the bulk rocks higher 0.5 are of magnetite-series whereas those of ilmenite-series being much lower than 0.5. Magnetite-series granites were, consequently, formed under conditions of higher oxygen fugacity than the ilmenite-series (Ishihara, 1971a; Ishihara and Terashima, 1977; Ishihara, 1978) and are considered to have been generated in a deeper level (upper mantle and lower crust); whereas the ilmenite-series generated in the middle to lower continental crust. Besides these, ilmenite-series can be easily distinguished in the field from magnetite-series by rather lower magnetitc susceptibility, assemblages of ferromagnesian-silicates, color of biotite (Ishihara, et al., 1978). If these empirical criteria are applied to the granites of Phuket Plutons, it is no doubt to conclude that the biotite granites (i.e. G-1, G-2) are of magnetite-series characterized by high Fe_2O_3/FeO ratio (average 0.47, maximum 0.71), the presence of several greenish brown biotite, primary sphene, absence of primary muscovite whereas the biotite-muscovite varieties (i.e. G-3, G-4 and G-5) being ragarded as ilmenite-series approved by the abundance of muscovite, reddish brown biotite, absence of sphene, and rather low Fe_2O_3/FeO ratio (average 0.2, maximum 0.05).

8.3 Petrological Aspects

The D.I. (differentiation index) of Thornton & Tuttle (1960), is a useful petrologic feature used by Flinter, et. al., (1972) for grouping 131 plutonic rocks of the New England igneous complex as either tin-bearing or - barren granitic rocks. They found that D.I. is highly positively correlated with SiO_2, not so well correlated with Al_2O_3 and K_2O, uncorrelated with Na_2O, as well as shows a good inverse relationship (negative correlation) with CaO, FeO, TiO_2, and MgO. Such cases of data seem to be in accordance with those of Phuket Plutons (Figure 25a, 25b and 25c). Flinter, et al., (op. cit.) concluded that tin-minerlization occurs in granitic rocks where D.I. is over 85 (most of the D.I. of G-3, G-4 and G-5 of Phuket Plutons exceed 85). Smith and Turek (1976) introduced a recalculated petrological index, P.I. (observed volume percent of biotites as total ferromagnesian minerals) to selecting 75 Dev nian granitic rocks in Nova Scotia, East Canada which are most likely to be tin-bearing. They concluded that muscovite-biotite granites as well as alaskites and leucogranites having P.I. < 4 are tin-bearing granites and biotite granites and granodiorite rocks having P.I. > 4 are tin-barren granites. The only granites of Phuket Plutons that meet these requirements completely (i.e. average D.I. $\sim$ 90.5, P.I. $\sim$ 4) are the finer-grained biotite-muscovite granites (G-4 and G-5). The coarser-grained biotite-muscovite granites (G-3) have lower D.I. (87.8) and slightly high P.I. ($\sim$10) whereas the biotite granites (G-1 and G-2) have much lower D.I.

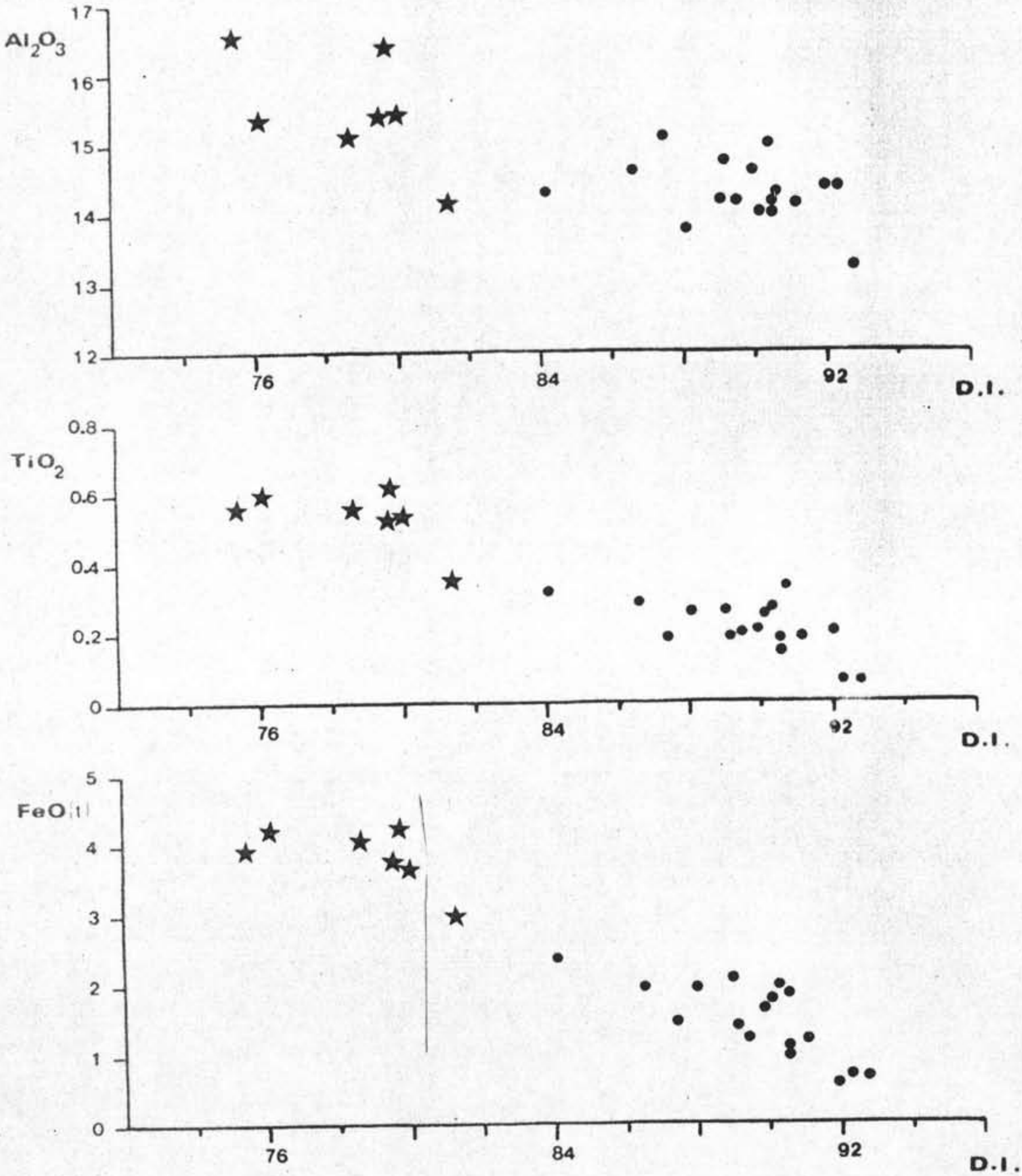


FIGURE 25a. VARIATION DIAGRAMS OF Al_2O_3, TiO_2 and FeO(t) VERSUS DIFFERENTIATION INDEX (D.I.) OF GRANITES OF PHUKET PLUTONS.

★ less silicic group (G-1, G-2) ● more silicic group (G-3, G-4, G-5)

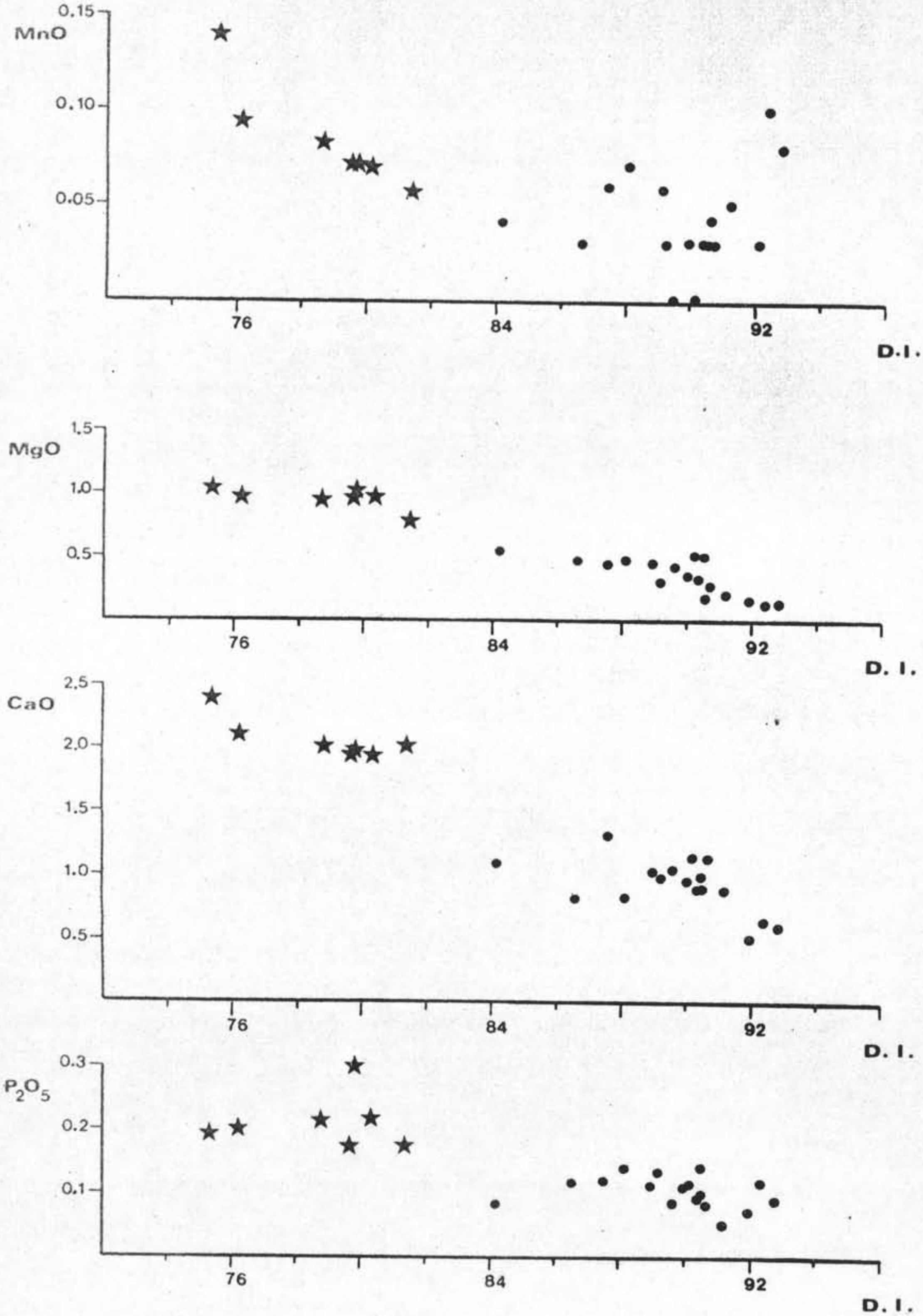


FIGURE 25b. VARIATION DIAGRAMS OF **MnO, MgO, CaO, and P_2O_5** VERSUS DIFFERENTIATION INDEX (**D.I.**) OF GRANITES OF PHUKET PLUTONS.

★ less silicic group (G-1, G-2) ● more silicic group (G-3, G-4, G-5)

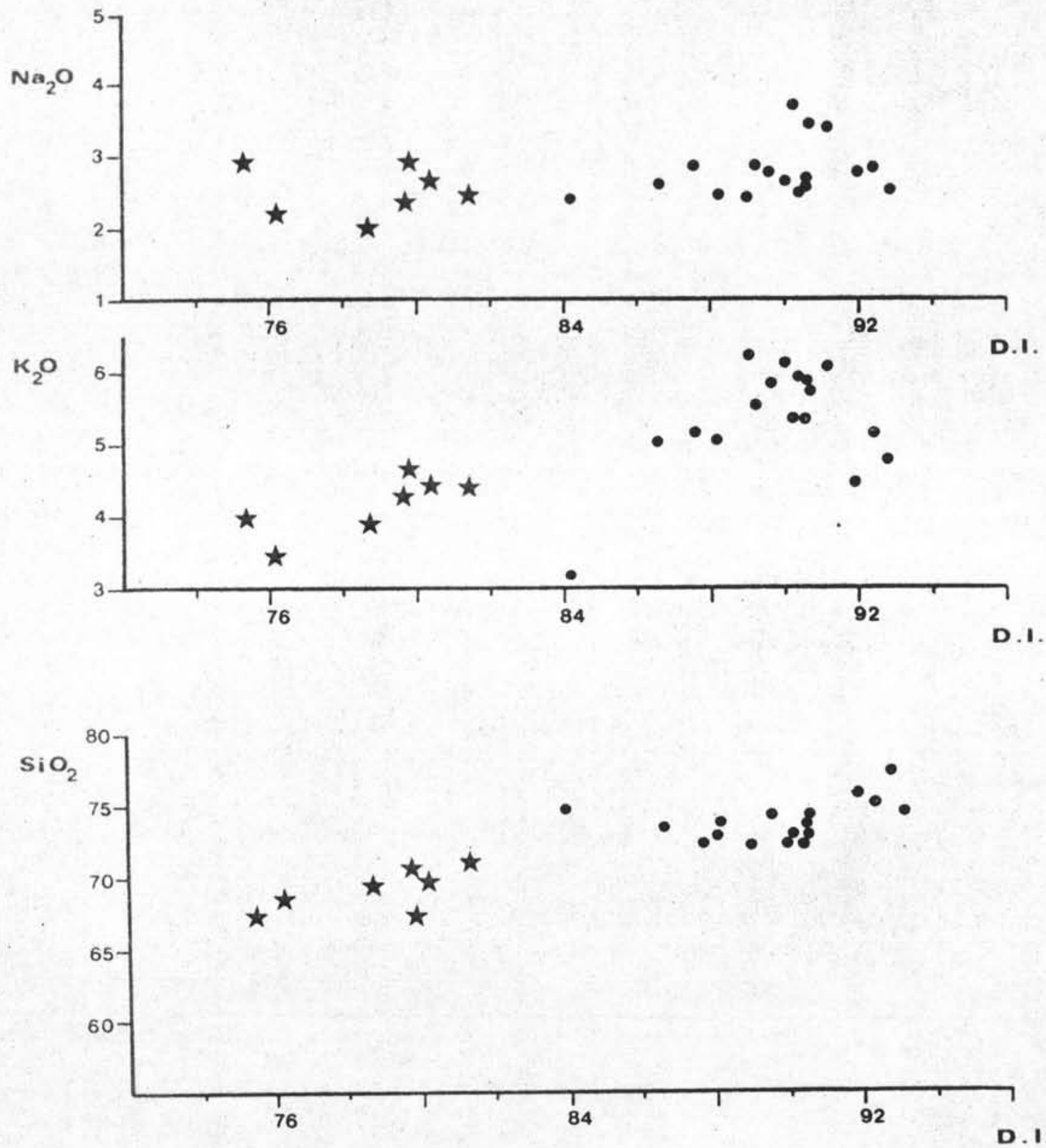


FIGURE 25c. VARIATION DIAGRAMS OF Na_2O, K_2O, and SiO_2 VERSUS DIFFERENTIATION INDEX (D.I.) OF GRANITES OF PHUKET PLUTONS.

★ less silicic group (G-1, G-2) ● more silicic group (G-3, G-4, G-5)

(average 78.78) and relatively higher P.I.) (average 15.4). These observations suggest that G-4, G-5 and probably G-3 are the most favourable for tin-mineralization.

It had been shown for two decades that metasomatic and hydrothermal alterations are important metallogic indicators of tin-mineralization (Atanyakanon, 196 1 ; Beus & Zalashkova, 1962; Juniper & Kleeman, 1979). According to Aranyakanon (1961), the Haad Sompan granites crystallized originally has been altered in the later stages of cooling by permeating gases. Sn and W are introduced in the gaseous stage at the same time. Janecka & Stemprock (1967) found that the granitic rocks of the Bohemian Massif with tin deposits associated are characterized by magmatic metasomatism or greisenization (decompositions of feldspar and biotite, formation of quartz, muscovite, topaz, and ore minerals). Such metasomatic alterations are also found abundantly in granitic rocks of Saxonian Erzgebirge (G.D.R.) (Wasternack, et al., 1974) and of Finnish Rapakivi granites (Haapala, 1974) with which tin and related mineral deposits are associated.Groves (1972, 1974) observed little alteration in biotite-muscovite tin-bearing granites of Blue Tier Batholith. Aranyakanon (1961, 1978) and Stemprok (1979) suggested that secondary or deuteric alterations are as possibly major concentrators for tin and other rare metals and that these alterations may lead to changes in the normative compositions of the granites. The biotite-muscovite and mica-tourmaline granites (G-3, G-4 and G-5) of Phuket Plutons have undergone comparatively more alterations than biotite granites (G-1 and G-2). As shown in details in the petrographical studies, the alterations are characterized by chloritization,silification, and sericitization. Aranyakanon (1978) has further summarized that the porphyritic/coarser textures of parent granites enable to be altered to finer varietits. Such features also occur locally in granites of Phuket Plutons (e.g. at Khao Mai Tao Sip Song). As indicated in Figure 33a, the trends for change in normative composition of granites according to various postmagmatic alteration processes (Stemprok & Skvor, 1974) can be compared with plots of those compositions of granites of Phuket Plutons (Figure 33b). It is illustrated that all types of granites of Phuket Plutons have undergone more or less sericitization and G-3, G-4 and G-5 have been subjected to some silification as well.

8.4 Major Element Geochemical Characterization

A ternary plot, SiO_2 - (CaO + MgO + FeO) - (Na_2O + K_2O + Al_2O_3) used by juniper & Kleeman (1979) can be applied to define a Sn-mineralizing rock field of New England. Figure 26 show that G-3, G-4 and G-5 have been plotted within or close to the field of New England tin-bearing rocks and G-1, G-2 plots falling within the tin-barren field. Though tin-bearing field of Phuket Plutons and New England are not in the same position, both of which show a separation distinguished from those of tin-barren.

Rattigan (1964) used the ternary plots (Na + K) - Fe - Mg and Na - Ca - K to infer a trend of magmatic evolution and to clearify tin-bearing from tin-barren fields. Figure 27 and 28 show the groups of G-1, G-2 and of G-3, G-4 and G-5 plotting comparatively with tin-barren and -bearing field of New England granites. Though the two fields of tin-bearing as well as of tin-barren are not coincided exactly with each

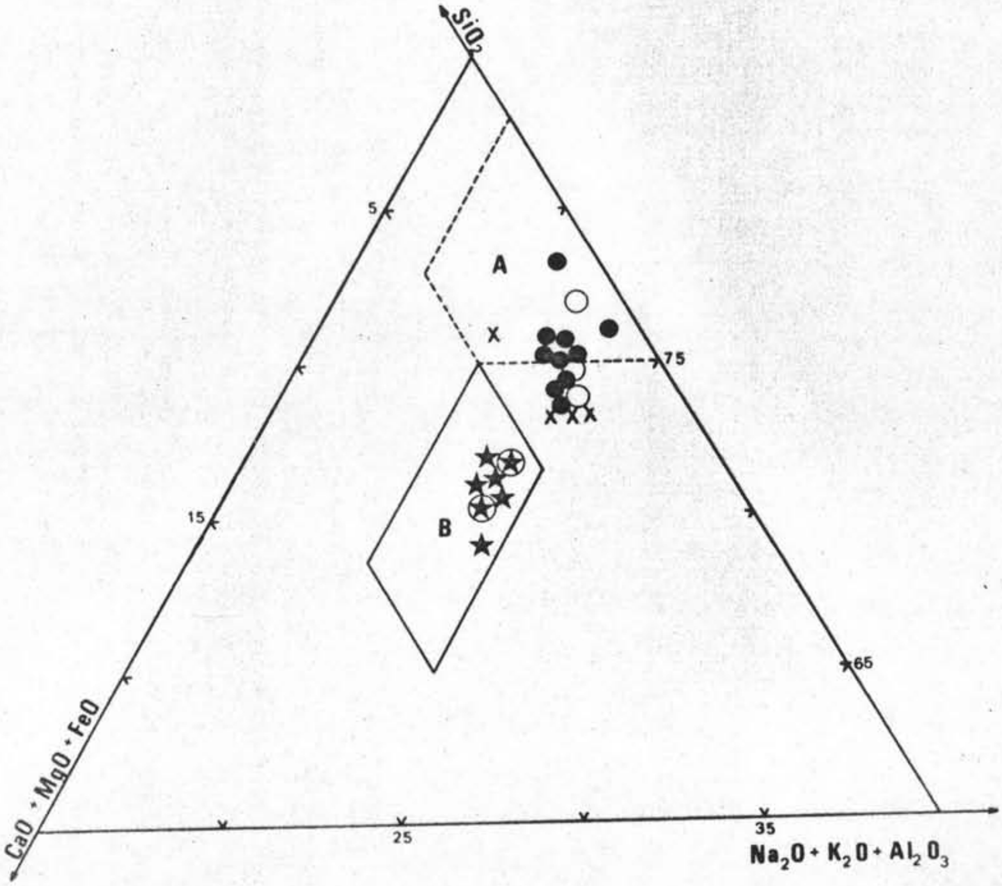


Figure 26. TERNARY SYSTEM $SiO_2 - [CaO + MgO + FeO] - [Na_2O + K_2O + Al_2O_3]$ FOR GRANITES OF PHUKET PLUTONS COMPARED WITH [A] TIN-BEARING AND [B] TIN-BARREN NEW ENGLAND GRANITES [JUNIPER KLEEMAN, 1979].

★ G-1 ⊛ G-2 X G-3 ● G-4 ○ G-5

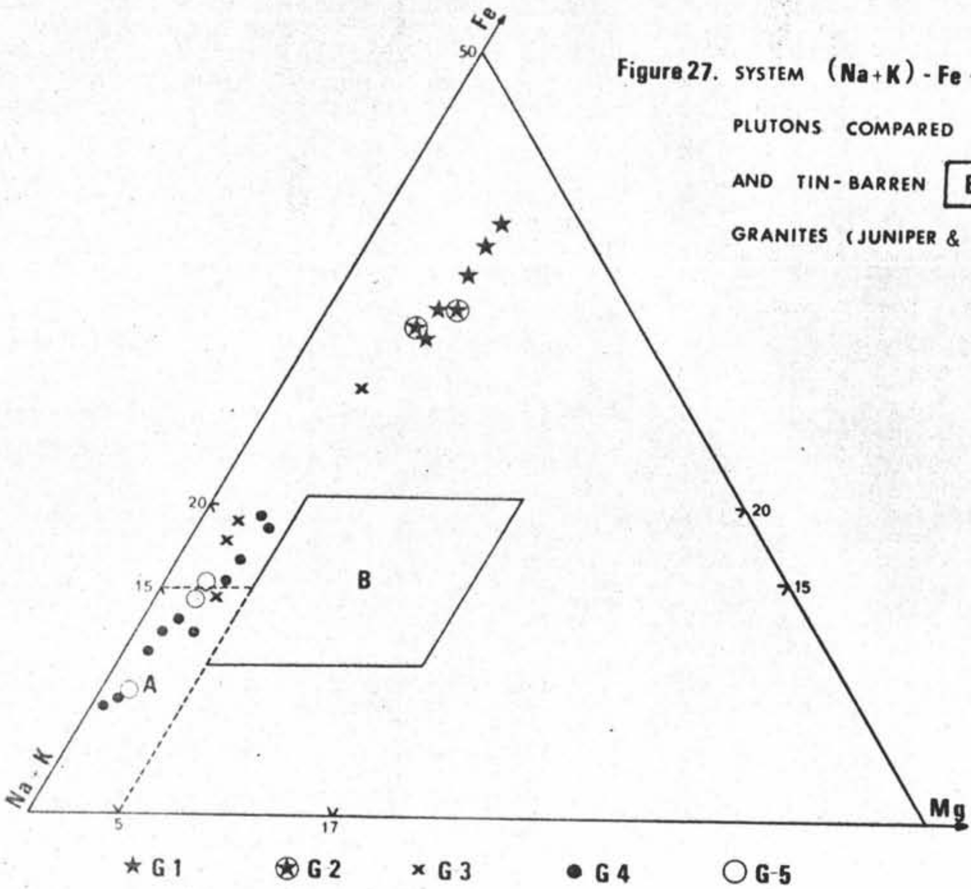


Figure 27. SYSTEM (Na+K) - Fe - Mg FOR GRANITES OF PHUKET PLUTONS COMPARED WITH TIN-BEARING [A] AND TIN-BARREN [B] GRANITES OF NEW ENGLAND GRANITES (JUNIPER & KLEEMAN, 1979).

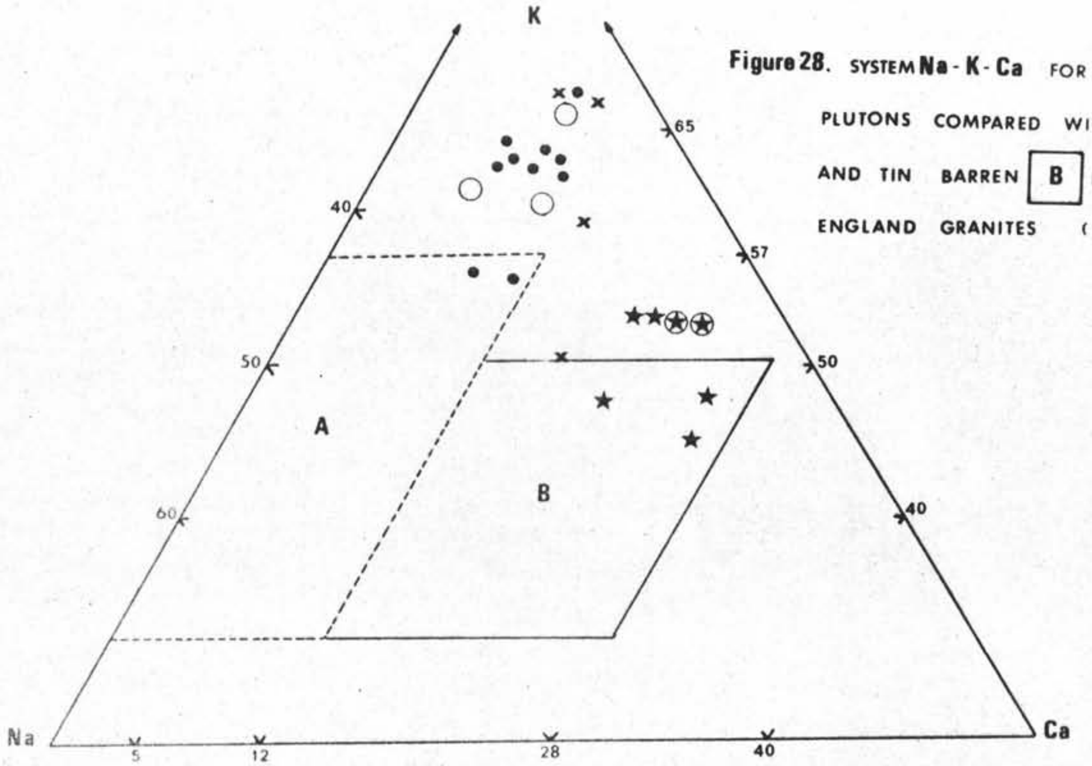


Figure 28. SYSTEM Na - K - Ca FOR GRANITES OF PHUKET PLUTONS COMPARED WITH TIN BEARING [A] AND TIN BARREN [B] ROCKS OF NEW ENGLAND GRANITES (JUNIPER & KLEEMAN, 1979).

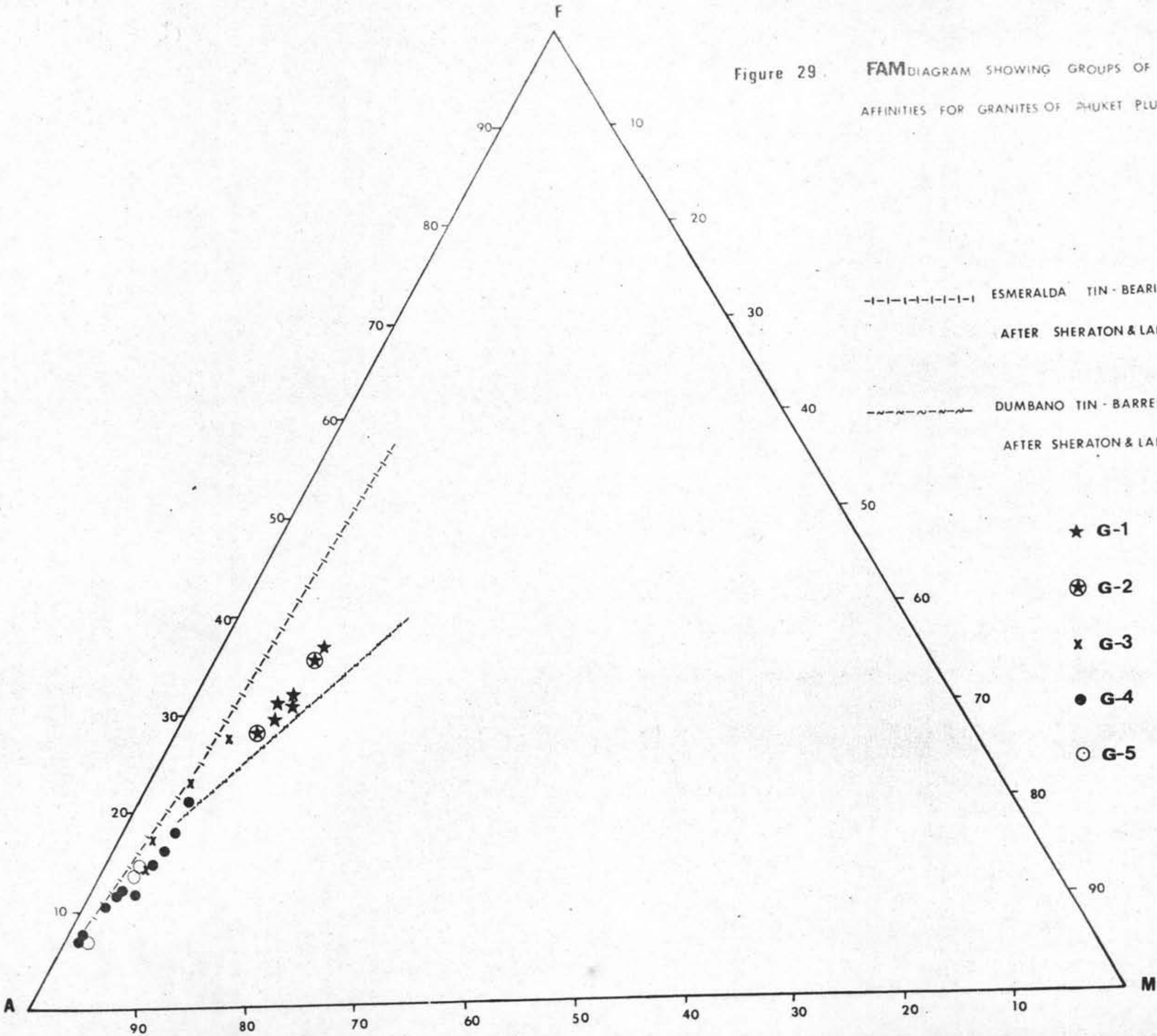


Figure 29. FAM DIAGRAM SHOWING GROUPS OF CAL-ALKALINE AFFINITIES FOR GRANITES OF PHUKET PLUTONS

other, those of tin-bearing groups can be discriminated from those of tin-barren ones. As shown in Figure 29, the Phuket Plutons have been plotted in the FAM triangular diagram. It was shown that G-1 and G-2 trend is close to that of Dumbano tin-barren granites (Sheraton & Labonne, 1978) and G-3, G-4 and G-5 trend close to that of Esmeralda tin-bearing granites (Sheraton & Labonne, op. cit.).

Aranyakanon (1961), Groves (1972) reported that the tin-bearing granites commonly higher in SiO_2 content and lower slightly in K_2O content whereas many authors (Gotman & Rub, 1961; Rattigan, 1963; Hesp & Rigby, 1974) demonstrated that tin-bearing granites are usually highly potassic. Pitakpaiwan (1969) and Sheraton & Labonne (1978) have studied tin-bearing and -barren granites of Thailand and NE Queensland, respectively and indicated that the tin-bearing are usually higher in SiO_2 and K_2O content. Stemprok (1979) concluded that tin-bearing granites appear to be silica and K_2O-rich but depleted in other oxides, such conclusion is also resonable with the tin-bearing (G-3, G-4, and G-5) and tin-barren (G-1, G-2) granites of Phuket Plutons (see also Figure 13, Table 4a).

8.5 Minor-and Trace-element Geochemical Characterization

Trace elements offer some of the most reliable criteria for differentiating between a potential tin-bearing granite and one that is not. According to Tauson & Kozlov (1973), they have emphasized that not only must the original magma contains suitable concentrations of ore-forming elements, but also the suitable conditions of crystallization must exist to allow ore-forming solutions to evolve. They suggested that trace element concentrations and elemental ratios indicate the sources of

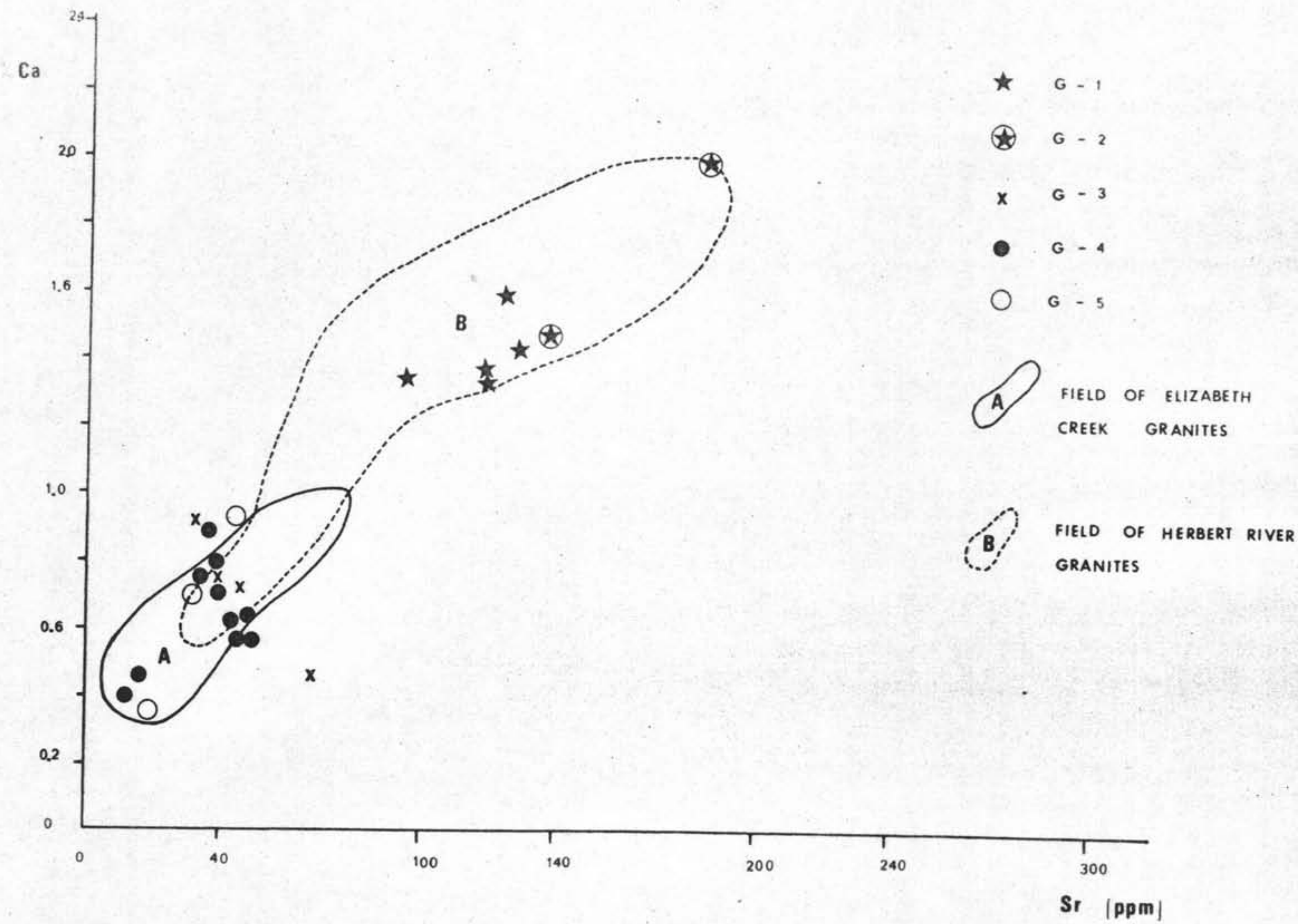


Figure 30. PLOT OF Ca AGAINST Sr OF GRANITES OF PHUKET PLUTONS COMPARED WITH ELIZABETH CREEK GRANITES AND HERBERT RIVER GRANITES (SHERATON & LABONNE , 1978).

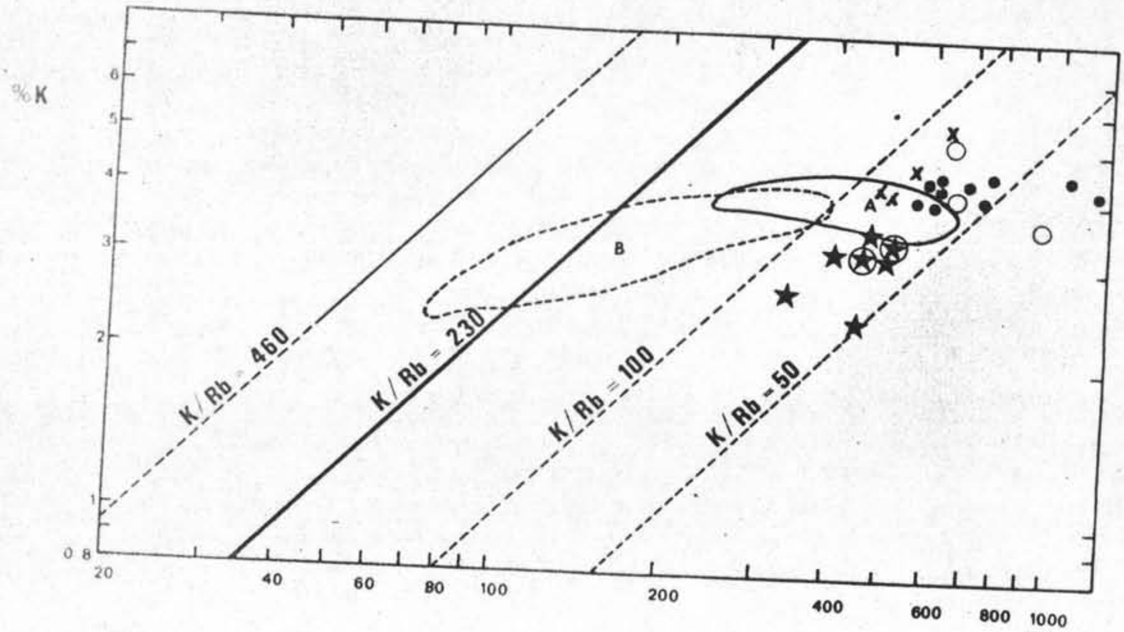


Figure 31. PLOT OF K AGAINST Rb OF GRANITES OF PHUKET PLUTONS.

RATIO OF CRUSTAL AVERAGE (AFTER TAYLOR 1965)

★ G-1 ⊛ G-2 x G-3 • G-4 ○ G-5 □ HIGHLY GREISENIZED GRANITES

(A) FIELD OF ALIZABETH CREEK TIN BEARING GRANITES

(B) FIELD OF HERBERT RIVER TIN BARREN GRANITES

(AFTER SHERATON AND LABONNE 1978)

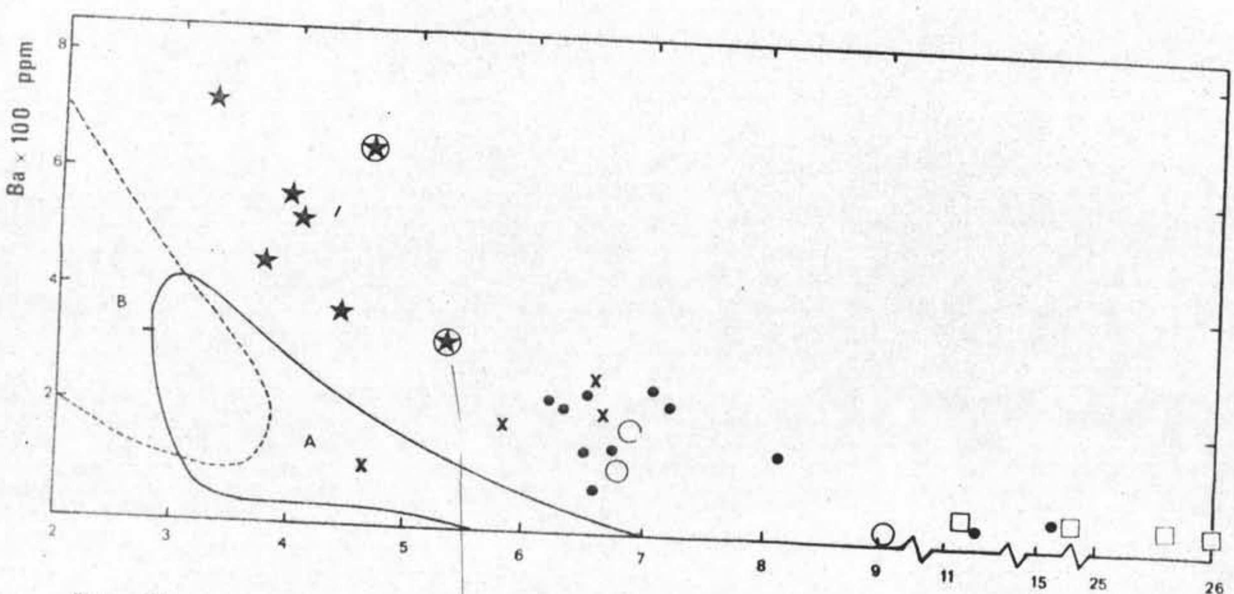


Figure 32. PLOT OF Ba AGAINST Rb OF GRANITES OF PHUKET PLUTONS.

a rock, its mode of origin, and also the evolution of the magma during crystallization. Tischendorf (1977) suggested that the average amounts of Rb present in mineralized granites tend to range from 380 to 780 ppm and are particularly tend higher than non-mineralized granites. Amazonite (rare-metal-bearing and albite-rich)granites of the Soviet Union, with which tin deposits are associated are enriched in Ta and Nb relative to the granites of other types (Zalashkova & Gerasimovskii, 1974). Tauson (1974) showed that there is a slight tendency of Y enrichment in tin-bearing granites of Transbaikalia zone (USSR). According to Klominsky & Absolonova (1974), the tin-bearing granites of Karlovy Vary Granite Massif (Czechoslovakia) show a distinct decrease in the concentration of Mg, Ca, Zr, and Ba probably caused by the secondary alteration (autometa-somatic stage). From the elemental concentration shown in Table 4b with relative to data described above, G-3, G-4 and G-5 are more or less equivalent to those tin-bearing granites of various regions while G-1 and G-2 do not show such tendency. Flinter and others (1972) and Groves & McCarthay (1978) reported that B and F or F-minerals is not neccessary, nor indicative of tin mineralization, whereas Garson, et al., (1975) and Ishihara, et al. (1978) in their studies on tin-bearing and - barren granite in Southern Thailand, including the area of investigation found that the presence of F and B are enriched in tin-bearing granites.

The Ba/Rb ratio has been reccommended by Tauson & Kozlov (1973) as the best indicator of mineraliation. Ratio of less than 1 is generally confined to late-stage highly fractionated granites that are often accompanied by tin deposits. Figure 31 illustrated Rb poltting against Ba of granites analyzed, the plots conform with the field of NE

Queensland tin-bearing and - barren granites (Sheraton & Labonne, 1978). Plimer and Elliot (1979) emphasized that granites associated with mineralization commonly have much higher Rb/Sr ratio (as a result of fractionation and alteration) than the unmineralized granites. The ratio is highest where alteration is most intense and mineral deposit is present. Sheraton & Labonne (1978) found that the Upper-Paleozoic Elizabeth Creek tin-bearing granites have average Rb/Sr ratio about 13.6 whereas the other Upper-Paleozoic tin-barren granites have the ratio about 3.2 A good aggrement of these two ratios (Table 3a, and 3c) are also found from the Phuket-Pluton granites. The G-3, G-4 and G-5 is favourably tin-bearing whereas G-1 and G-2 are absolutely not. Figure 30 shows that K/Rb ratio of granites analyzed are often considerably lower than the crustal average of 230 ppm (Taylor, 1965). The G-3, G-4 and G-5 granites can be grouped in the same field and distinguished from the G-1 and G-2 granites. The K/Rb ratios of the G-3, G-4 and G-5 granites are rather low (Table 3b and 3c), being of tin-bearing as compared with those of Elizabeth Creek tin-bearing granites. These ratios of G-1 and G-2 are relatively high and compatible with those of Herbert Creek tin-barren granites. The same geochemical correlation among these types of granites have been further done by using Ca values against Sr concentrations (Figure 32). It is found that the G-3, G-4 and G-5 granites are able to correlate with Elizabeth Creek tin-bearing granite whereas G-1 and G-2 usually conform with Herbert River tin-barren granites,

8.6 Sn Characterization

There has been considerably controversy concerning the concentration of Sn in rock samples (Sn_R) to characterize the granites which are

Table 7 Range and Averages of Sn Coneentration in Tin-bearing and-barren Granites

	Location	(ppm) Sn_R in tin-bearing granites	(ppm) Sn_R in tin-barren granites	Sources
1.	USSR	15-30	3-5	Barsukov (1957, 1967)
2.	Australian Granites	20	3.1	Rattigan (1963,1964)
3.	East Transbaikal, USSR	23.4	5	Ivanova (1969)
4.	Blue Tier Batholith, Tasmania	49	9	Groves (1972)
5.	Cullen Granites, Northern Territory	2-7	2	Ewers and Scott (1977)
6.	NE Queensland	7	3	Sheraton and Labonne (1978)
7.	SW Nova Scotia, Canada	19	8.7	Smith and Turek (1977)
8.	Erzgebirge, Germany	20-55	8-24	Tischendorf et al., (1974)
9.	Malaysia	15-40	5	Flinter (1969)
10.	New England, Australia	24	5	Juniper & Kleeman (1979)
11.	Emazoki & Kymi, S. Finland	13	5	Haapala (1974)
12.	S. Thailand	10(7-20)	10 (5-12)	Ishihara et al. (1978)
13.	Phuket-Phangnga, Thailand	12-55	3-10	Garson et al. (1975)

responsible for tin mineralization and to distinguish them from those which are not. The lack of reliable data has contributed to the dilemma. And tin element is, consequently, difficult to analyze, due to detection limit of the instrument, especially in a rock matriz as reported by Juniper & Kleeman (1979). However, many geology workers as mentioned in Table 7 believed that Sn_R values should be correlated with some mineralization and that tin-bearing granites have a greater Sn_R than tin-barren granites. According to Ivanova (in Vederpohl, 1969), Rattigan (1964), Barsukov (1957, 1967) and Ianova (1963) found tin-bearing granites to contain 15-30 ppm compared with 5 ppm for tin-barren ones, mostly with the detection limit of about 5 ppm. Hesp & Rigby (1974) noted that for all rocks in Tasman Geosyncline the ratio of the mean Sn_R in tin-bearing and -barren granites was around 7:1. Tauson (1975) reported the average Sn_R (6.3 ppm) of the tin-bearing is two times higher than those of tin-barren (2.9 ppm). Tischendorf (1977) and Stemprok (1979) showed that tin-bearing granites appear to contain Sn_R ranging from 6 up to 22 ppm, and those of the barren vary from 2 to 5 ppm. In the light of these conclusions, no surprising is, therefore, the fact that G-3, G-4 and G-5, especially greisen granites have a strong tendency to become tin-bearing while G-1 and G-2 have not. Figure 19 showing the plots of Sn_R versus SiO_2 of Phuket Plutons compared with the Australian granites (Rattigan, 1963; Sheraton & Labonne, 1978) indicated that the Phuket Plutons trend is higher than those of Australian granites. The explanation for this higher trend may lie in the realization that the high amount of Sn content in granites with which tin-deposits are associated exhibit the highly evolved geochemical characteristic in any given tin province (Pitakpaiwan, 1969). Otherwise, it might be that whether Sn mineralization occurs depend primarily on the physicochemical condition (e.g. temperature, pressure, pH, Eh) (Ewers & Scott, 1978) and geological environments such as types of wall rocks (Aranyakanon, 1969), occurrence of fracture zones (Black, et al., 1 978), degree of melting (Hutchison & Chakraborty, 1979) rather than the absolute concentration of Sn_R.

8.7 Miscellaneous

According to Stemprok (1979), the tin-bearing granites usually from at rather low temperature and water pressure, as indicated by plotting normative quartz (Q), albite (Ab) and orthoclase (Or) in the triangular diagram used by Tuttle & Bowen (1958). The study of the Phuket Plutons reveals that all the analyzed rocks contain greater than 75% normative Q+Ab+Or. The G-1 and G-2 granites have the average normative nearly 77.0%, G-3 about 86.5%, and G-4 as well as G-5 close to 89%. These proportional ratios of normative compositions have been plotted on the experimentally derived phase diagram in the systems Q- Ab - Or H_2O (after Tuttle & Bowen, 1958) and Q - Ab - Or - An - H_2O (after James & Hamilton, 1969). The two enclosed fields represent Esmeralda tin-bearing granites, NE Queensland (Sheraton & Labonne, 1978) and the biotite-muscovite granites of Blue Tier Batholiths, Tasmania (Groves, 1972). The latter contain normative corrundum (i.e. alumina excess) and are reported as tin-bearing rocks, some granites of Phuket Plutons also contain some normative corrundum (Table 2). The analyzed samples plot in a restricted compositional field in the Tuttle & Bowen system, and tend to cluster near the quartz-feldspar boundary at fairly low P H_2O (nearly o.5 kb up to 2.5 kb) (Figure 33b). It is apparent that the G-3 and G-4 granites plot close to the region of the ternary minimum at 500-1,000 bars of this system. Such field is also coincided with that of tin-bearing granites of NE Queensland and Tasmania, suggesting that low-water pressure prevailed during crystallization. Because of the high K/Na ratio (Table 2a, 2b and 2c) the plots lie on the Or side of the ternary system. Similar conclusion was drawn also by Stemprok & Skvor (1974) that the common tin-bearing granite (biotite, muscovite, and two-mica granites) are closely grouped over the low temperature minima of the feldspar-quartz cotectic of the Ab-Or-Q normative diagram. The G-1 and G-2 granites, on the other hand, plot close to the ternary minima between 1,000 to 2,500 bars water pressure, indicative of higher water pressure during crystallization. In the quartz-saturated ter ary system at 1 kb P H_2O (Figure 34), the granitic rocks form a fairly well defined trend extending from a point inside the plagioclase field at temperature nearly 800°C (i.e., G-1 and G-2) towards the boundary curve at 730°C (i.e., G-3) and within the alkaline feldspar field (G-4 and G-5) near the ternary minimum of the granite system.

It is important to conclude here from the above data that the G-4, G-5 and probably G-3 granites plot close to the ternary minima of low temperature and water pressure while the G-1 and G-2 granites are plotted in the higher water pressure field. According to their sizes of exposures (Map 2), grain-size variation and abundances of pegmatites and aplites, the coarser-grained granites (i.e., G-1) are deeper phase with relative to the finer-grained varieties (i.e., G-4, G-5). Not surprising is, therefore, to state that G-3, G-4 and G-5 become more tin-bearing than G-1 and G-2.

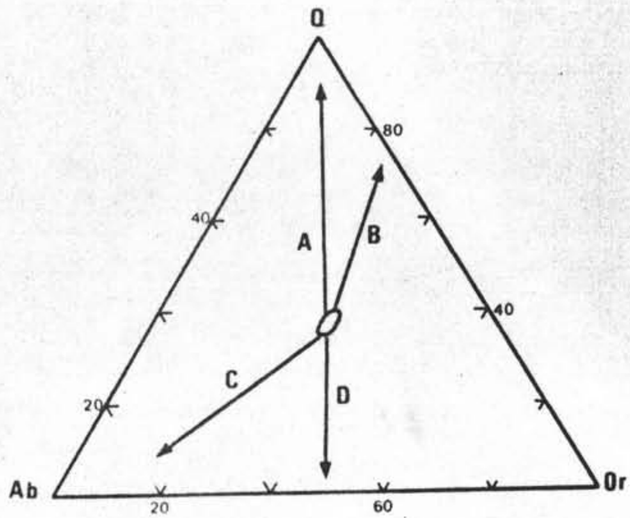


Figure 33a. THE TRENDS FOR CHANGE IN NORMATIVE COMPOSITION OF GRANITES ACCORDING TO THE INDICATED POSTMAGMATIC ALTERATION PROCESSES (STEMPROK & SKVOR, 1974).

A = SILICIFICATION

B = SERICITIZATION & GREISENIZATION

C = POTASH FELDSPATHIZATION

D = ALBITIZATION

FIGURE 33 b. Normative Q-Ab-Or diagram for granites of Phuket Plutons

SHOWING QUARTZ FELDSPAR FIELD BOUNDARIES AT 500 & 3,000 BARS P_{H_2O} AND POSITION OF QUATERNARY ISOBARIC MINIMA (AFTER TUTTLE & BOWEN, 1958).

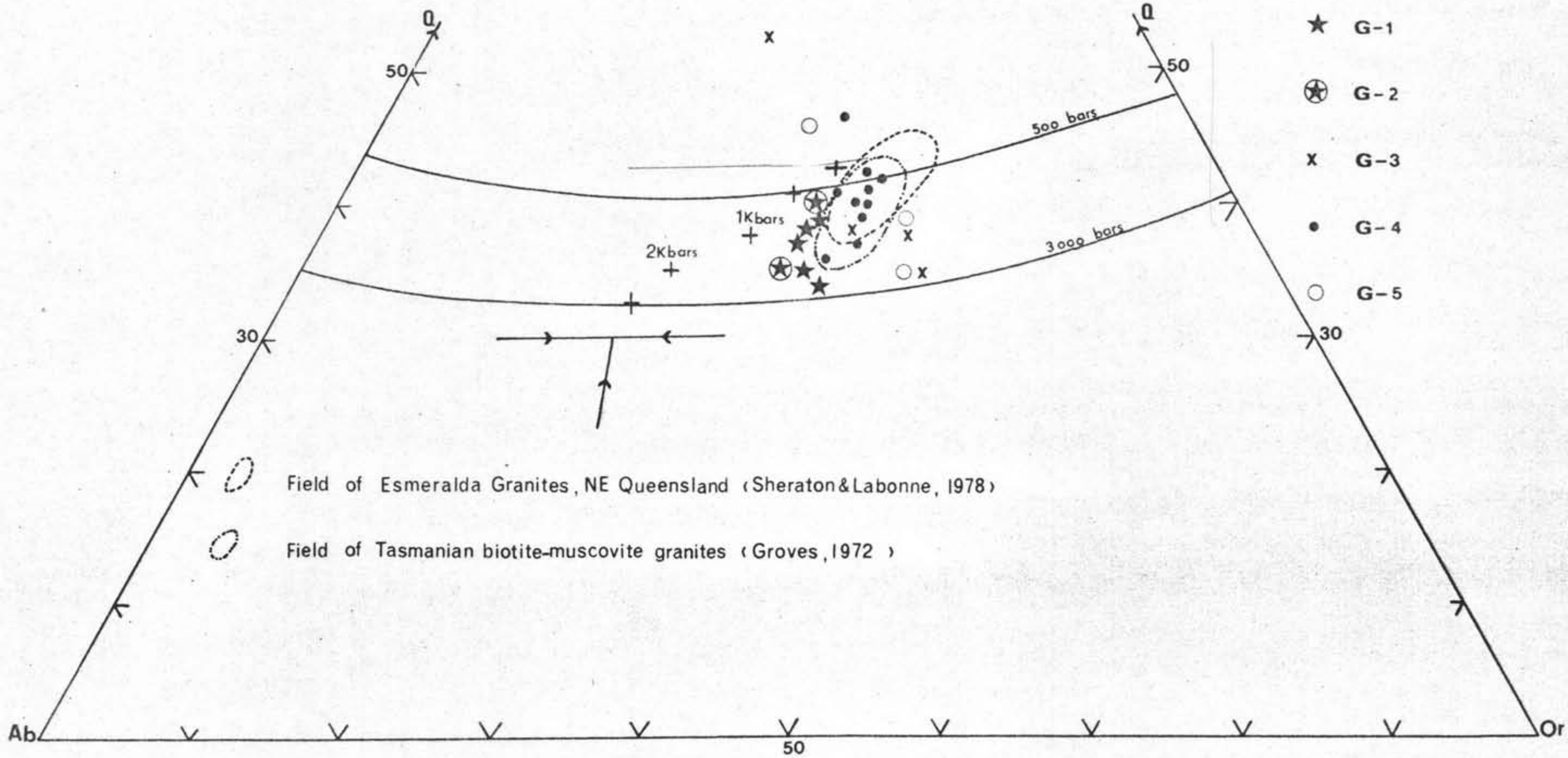


FIGURE 34. Normative Ab-Or-An diagram for granites of Phuket Plutons

SHOWING PART OF THE LIQUIDUS SURFACE OF QUARTZ SATURATED FELDSPAR SYSTEM AT 1,000 BARS P_{H_2O} PROJECTING ON TO THE Ab-Or-An OF THE TETRAHEDRON (AFTER JAMES & HAMILTON, 1969).

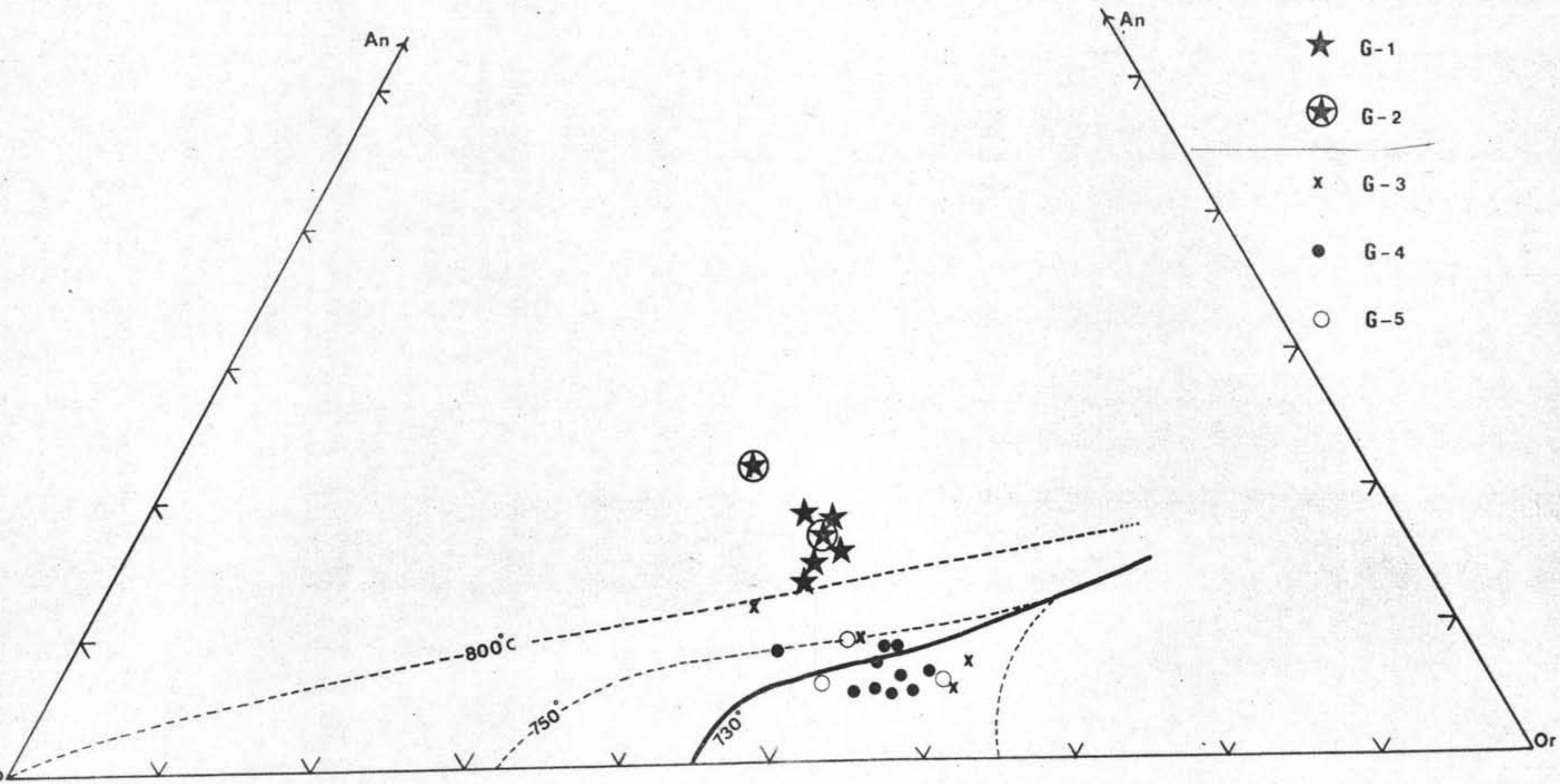
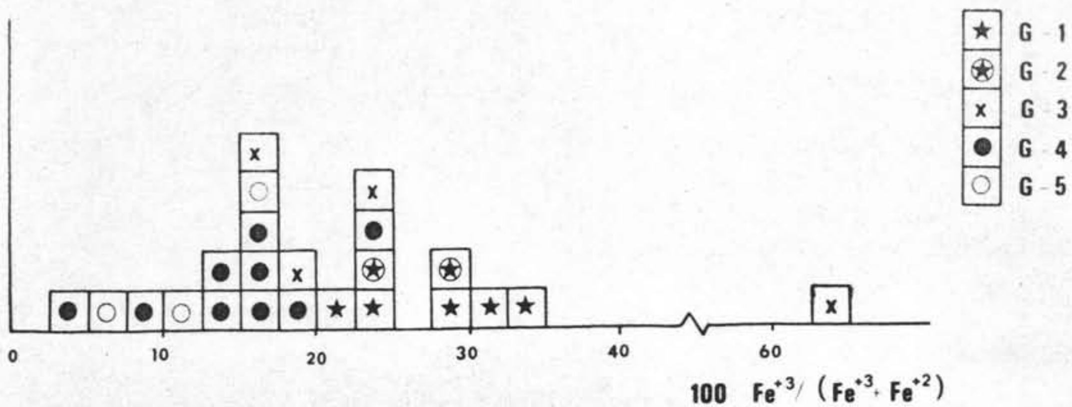


Figure 35. OXIDATION RATIO IN TERMS OF PERCENTAGE OF $Fe^{+3}/(Fe^{+2}+Fe^{+3})$.



The granites of Phuket Plutons have been further regrouped according to whether they have been derived from (meta)-sedimentary source rocks (s-type granites) or by the differentiation of igneous source rocks (I-type granites) (Chappel & White, 1974). According to their studies, such classification is relatively genetic but it is based mainly upon geochemical parameters which, when taken collectively, served to distinguish the two types. One of the main parameter is the ratio of K_2O to Na_2O, it is lower in I-types than S-type. The G-1, G-2 granites have an average K_2O/Na_2O ratio approximately 1.66, that of G-3 is 1.91, and those of G-4 and G-5 is nearly 2.1. The other parameter is the difference in the oxidation ratio $100Fe^{3+}/(Fe^{3+} + Fe^{2+})$, it is considerably higher in I-type than in S-types. As illustrated in Figure 35 the oxidation ratio differs markedly among the types of granites of Phuket Plutons. It is relatively higher in G-1, G-2 than in G-3, G-4 and G-5. This is presumably due to reduction of carbon (Flood & Shaw, 1975), hydrocarbon (White, et al., 1977) or sulfur (Hine, et al., 1978) present in the more silicic granite (i.e., G-3, G-4, G-5) originally from sediments during partial melting or progressive metamorphism. The low Fe_2O_3/FeO of the S-type is reflected in the reddish brown biotite and possibly, ilmenite (Hine, et al., 1978). Such biotite appears to be characterized of G-3, G-4 and probably G-5.

Mineralogy of granites, are petrographically distinguished S-from I-types. I-types are characterized in thin sections by the presence of primary sphene, allanite, hornblende, greenish brown biotite, long slender apatite, weakly developed pleochroitic haloes of zircon as well as zoned and complex-twinned plagioclase (White & Chappel, 1977). All these minerals and their characteristics, except hornblende, are found abundantly in the G-1 and G-2 granites. The typical minerals found in S-type are reddish brown biotite, equigranular apatite, zircon with dark pleochroitic haloes, muscovite, homogeneous or weakly zoned plagioclase, cordierite, garnet, and ilmenite (White & Chappel, 1977). All these minerals with an exception of cordierite are found scatterly in thin sections of granites belonging mostly to G-3, G-4 and G-5.

From the mentioned criteria used for granitic rocks classification of Chappel & White (1974) and of Ishihara (1977) (Section 8.2), it should be noted here also that these two classification of granites are approximately equivalent to each other. No surprising is, therefore, to conclude also that the biotite granites (G-1 and G-2) are likely to be I-type or magnetite-series granites and the biotite-muscovite granites (G-3, G-4 and G-5) are of S-type or ilmenite-series granites. Tin mineralization is frequently confined to the highly silicic part of the 'S-type' or 'ilmenite-series' granites whereas 'I-type or 'magnetite-se series' are responsible for tungsten, molybdenum, and porphyry copper mineralization (Chappel & White, 1974; Ishihara, 1977; beckensale, 1979). Anatexis of sialic crust is capable of yielding highly evolved SiO_2 and K_2O rich granites with which tin deposits are known to be associated (Hutchison & Chakraborty, 1978, Sheraton & Labonne, 1978). The fact that all granites of crustal origin are not tin-bearing suggests that the abundances of tin in crustal rocks is variable, due perhaps to highly irregular distribution of tin-containing silicates and oxides phases such as biotite, muscovite, tourmaline, zircon, ilmenite, and magnetite. Consequently, tin-bearing granites is likely to be the result of multi-stage processes; and the final stage being the resulting or reactivation of the tin-enriched part of the sialic crust. The geochemical data of the younger granites (G-3, G-4 and G-5) enables to prove such statement.