With the compliments of the authors.

Dr. Punya Charusiri

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Petrological and geochemical studies of granites of Kathu Plutons of Phuket Island, Southern Thailand

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Abstract: Approximately three-fourth of the area, 210 sq km, in the central part of Phuket Island is covered with granitic rocks of Kathu Plutons which range in ages from Cretaceous to Tertiary. Five types of granite are recognized in the field, namely, coarse-grained porphyritic biotite granite (G-1), fine-to medium-grained biotite granite (G-2), medium-to coarse-grained mica granite (G-3), fine-to medium-grained mica granite (G-4), and fine-grained mica-tourmaline granite (G-5).

The G-1 granites are the major phase and are composed mainly of plagioclase, biotite, microline, quartz, sphene, and allanite. The non-porphyritic G-2 granites are mineralogically similar to the porphyritic G-1 granites. The G-3 granites are distinguished from the G-1 and G-2 granites by the lower color index and the presence of muscovite, tourmaline and garnet. The G-4 and G-5 granites are petrographically similar to the G-3 granites except for the presence of commonly unzoned plagioclase and the widespread occurrence of muscovite, tourmaline, and fluorite. Intense effects of metasomatic and pneumatolytic alterations are also additional characteristics of the G-4 and G-5 granites. The contact relationships of the G-1 & G-2 with the G-3, G-4 and G-5 are sharp in many parts of the area.

Petrochemically, the granites are peraluminous. The G-1 and G-2 granites are regarded as tin-barren granites whereas the G-4 and probably G-3 and G-5 are tin-bearing granites. The tin-bearing granites, compared with the tin-barren ones, are more intensely altered and are more differentiated as evidenced by higher contents of SiO_2, K_2O, Rb, Nb, and Sn and lower TiO_2, FeO (total), Al_2O_3, MgO, MnO, CaO, P_2O_5, Sr and Ba contents. The tin deposits are principally found in greisenized G-4 granites and pegmatites.

INTRODUCTION

Phuket, an island on the west coast of peninsular Thailand, is approximately 900 km south of Bangkok. The Phuket island is not only known as the most beautiful beach resort for tourism but also is known as the richest tin mineral resources of the country. Primary tin deposits are obtained from veins, dikes, and other forms of plutonic rocks on the highlands, while the secondary tin deposits are derived from placer and beach deposits of the lowlands. The origin of all types of deposits in this area are, however, believed to be related ultimately to the granites distributed throughout the island (Hummel and Phawandon, 1976; Pitakpaiwan, 1969). The purpose of this study is to explore in detail the petrology as well as the geochemistry of the granites in order to delineate the most proper phases, types, sequences, and characteristics of the tin-mineralized granites. The granites of the Kathu Plutons in the central part of the Phuket Island have been chosen as a suitable area for this purpose as most of the tin mines are concentrated around this area.

Geology of the Phuket Island

Geology of the Phuket Island (Figure 1) is described following the works of Hummel and Phawandon (1976) and Charusiri (1980). The N-S elongate Phuket island

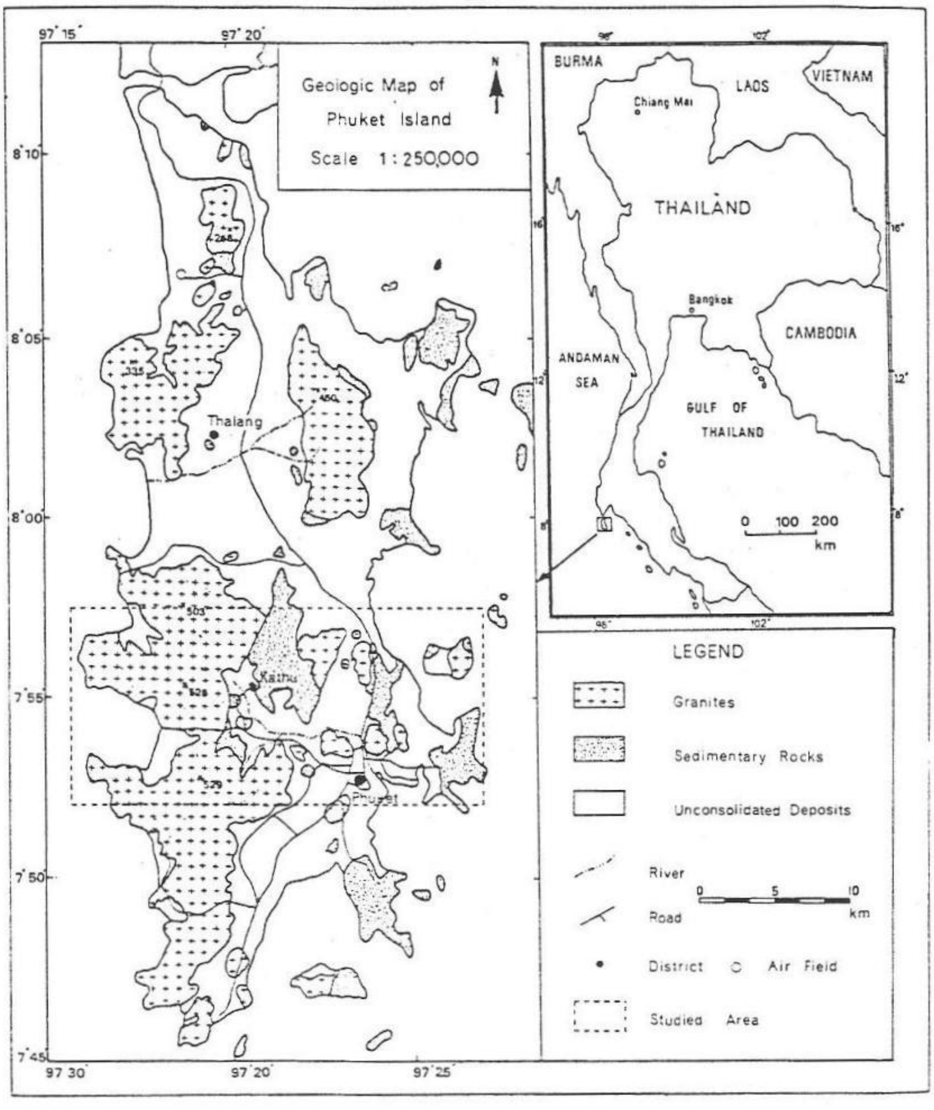


Fig. 1. Locality map of the studied area.

is composed mainly of two major rock types, i.e. sedimentary and granite rocks. The sedimentary rocks referred to as Phuket Series (Brown *et al.*, 1951) or Phuket Group (Mitchell *et al.*, 1970) of Permo-Carboniferous age (Ridd, 1971 a; 1971 b; Sawata *et al.*, 1975; Piyasin, 1975; Mantajit, 1978) are mudstone, pebbly mudstone, conglomeratic shale, siltstone and sandstone of various types (Charusiri, 1980). They are intruded extensively by large masses of granitic plutons which occupy the western portion of the island. The granitic rocks vary in compositions and physical appearances. Biotite granite is by far the most dominant type. The granitic rocks were considered to be of Mesozoic age by Hummel and Phawandon, 1976. However subsequent Rb-Sr and K-Ar dating of the whole rock and minerals by a number of workers suggests that the granites are mostly of Cretaceous age with rejuvenation due to the tectonic event in Tertiary (Pitakpaiwan, 1969; Snelling *et al.*, 1970; Bignell, 1972; Garson *et al.*, 1975; Beckinsale, 1979; Suensilpong and Putthapiban, 1979; Ishihara *et al.*, 1980; Beckinsale and Nakapadungrat, 1981).

There are numerous varieties of late magmatic derivations of granites e.g., aplites, pegmatites and quartz veins in this area. Some of them carry tin and tungsten minerals in volume large enough to form economic ore deposits. These tin-mineralized minor intrusions are aligned in the NNE direction (Charusiri, 1980). The tectonic setting of the tin-mineralized granite has been discussed by Garson *et al.*, (1975), and Suensilpong and Putthapiban (1979).

GEOLOGY AND PETROGRAPHY OF KATHU PLUTONS

Granitic rocks cover more than two-third of the total surface exposures in the area (Figure 2). The specific term "Kathu Plutons" applies to all granitic rocks which occur in the mapped area and its vicinity. The Kathu Plutons are composite. The overall shapes of the plutons are elongate more or less in a N-S direction. The contact boundaries between the granites or between the granites and sedimentary rocks of the Phuket Group are commonly sharp in many parts of the area.

As shown in the geological map, the granitic rocks of the Kathu Plutons have been collectively grouped, based upon filed investigation, into 5 types from older to younger as :

(1) Coarse-grained porphyritic biotite granites (G-1)

(2) Fine-(to medium-) grained biotite granites (G-2)

(3) Medium-(to coarse-) grained two mica granites (G-3)

(4) Fine-(to medium-) grained two mica granites (G-4)

(5) Fine-grained mica tourmaline granites (G-5)

Futhermore, the granitic rocks of the Kathu Plutons are also classified following the recommendation of the IUGS for the nomenclature of plutonic rocks (Streckeisen, 1973). They are all considered to be granites according to the modal percentages of quartz, alkali feldspar, and plagioclase (Figure 3). The biotite granites (G-1 & G-2) plot on the monzogranite subfield whereas the biotite-muscovite granites (G-3, G-4

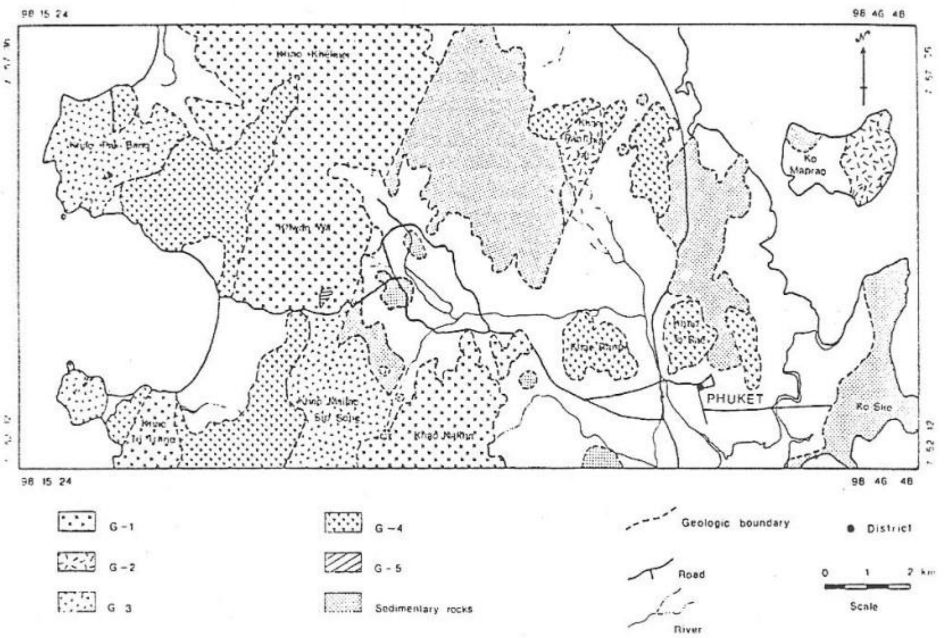


Fig. 2. Geology of the studied area.

and G-5) are predominantly located in the monzogranite subfield and subordinate in the syenogranite subfield.

Coarse-grained Porphyritic Biotite Granite (G-1)

The G-1 granites collectively occupy about 45 percent of the surface area of the Kathu Plutons. The main mass lies on the north-central part of the area and extends southwards to the central part. The minor plutons intrude in the south-central part. The terrain is invariably rugged with high relief, and characterized by steep-side walls with large accumulation of boulders.

In general the rock is highly porphyritic and more or less foliated. The foliation, defined by the arrangement of feldspar and mafic minerals of groundmass, trends generally in the NNW-SSE direction. Schlierens are common whereas the mafic mineral inclusions are relatively rare.

Petrographically, the texture of the G-1 granite is typically coarse-grained hypidiomorphic inequigranular locally grading to medium-grained allotriomorphic variety. The average total mafic mineral content (C.I.) is 13.6%. Mineralogically, quartz (av 27%) is present as anhedral, interstitial grains, and crystal aggregates. Myrmekitic quartz is very common. K-feldspar is microcline (av 27%) and always occurs as phenocryst with perthitic texture. It usually contains plagioclase and biotite

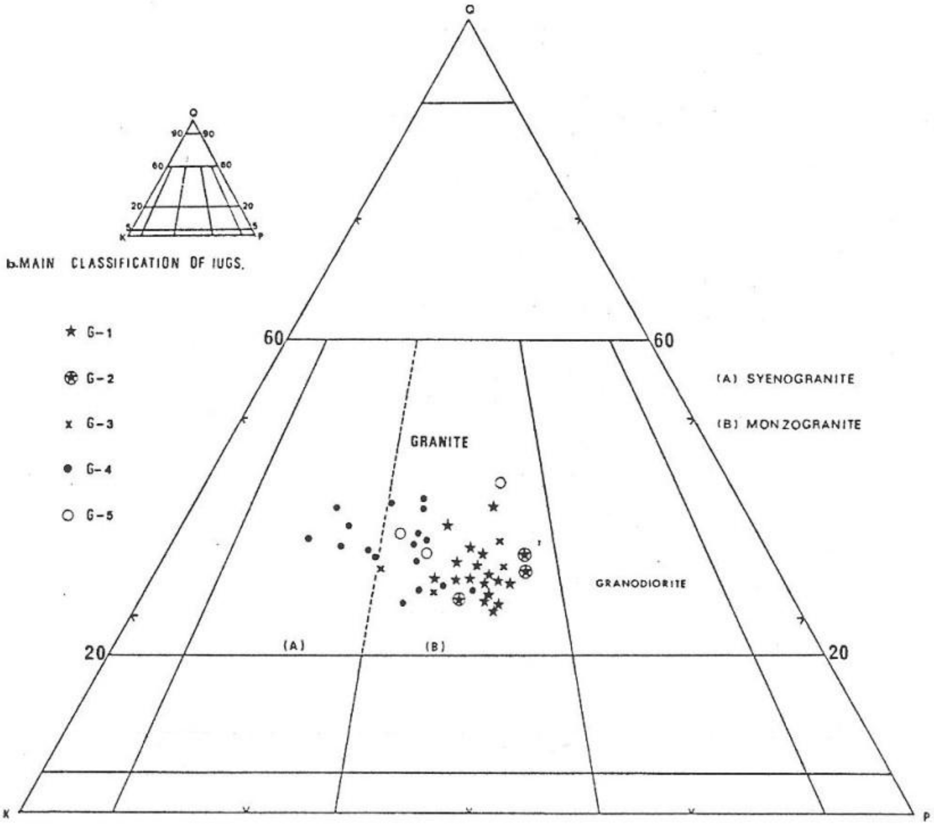


Fig. 3a. Plots of modal compositions [quartz, alkali feldspar and plagioclase] of granites of Phuket plutons on a QKP variation diagram used by the IUGS. Subcommission on the systematics of igneous rocks (Streckeisen 1973).

inclusions. Plagioclase (av 31 %) is always zoned (An_{36} core-An_{26} rim) and slightly altered. Biotite (av 13 %) exhibits strong greenish brown to brown pleochroism. Sphene is the most important accessory mineral. Allanite, apatite, zircon and opaques are the other accessories.

The G-1 granites are believed to be the primary and major phase of the Kathu Plutons.

Fine- to Medium-Grained Biotite Granite (G-2)

The G-2 granites are exposed as several small separated intrusions in the eastern part of the area. Field observations reveal that the G-2 granite is intruded by the G-4 and G-5 granites. The exact relationship between the G-2 granite and the G-1 granite is still unclear due to the fact that the actual contacts between these two granites have not been observed. However, because of their similarities in mineralogy and geochemistry, it is believed that the G-2 granite was formed at the same period as the G-1 granite.

In general, the G-2 granite (C.I. 15.7 %) is more mafic than the G-1. The texture is fine-to medium-grained, equigranular to slightly porphyritic and usually hypiodiomorphic. Microscopically, quartz (26 %) and microcline (27 %) occur as anhedral grains. Plagioclase (35 %) is highly zoned (An_{45}core–An_{27} rim). Biotite (16 %) is the only mafic mineral and muscovite (1 %) is of secondary type. Allanite, sphene, apatite are the major accessories.

Medium- to Coarse-grained Two Mica Granite (Slightly Porphyritic) (G-3)

The G-3 granite makes up about 15 % of the surface exposures of the Kathu Plutons, and occurs as two separate stocks in the western part of the area. This granite is in contact with the G-4 granite in many places either as gradational or faulted. Contacts between the G-3 and the (meta) sedimentary rocks are sharp in several places, particularly at the eastern slope of Khao Mai Tao Sip Song.

Megascopically, the G-3 (C.I. 12 %) appears to be more silicic than the G-1. Some are slightly porphyritic and foliated. Field observations indicate, however, that the G-3 can be distinguished from the G-1 by its mainly non-porphyritic texture as well as by the presence of muscovite and tourmaline. Microscopically, quartz (27 %) is subhedral and forms aggregates. Granophyric quartz is also common. Microcline (31 %) occurs as unaltered anhedral grains in the groundmass and as subhedral rectangular phenocrysts. Plagioclase (29 %) forms small subhedral tabular crystals occasionally with corroded rims. Some grains are altered by sericitization and kaolinization. Anorthite content ranges from An_{27} to An_{10}. Biotite (12 %) with brown pleochroism usually occurs as subhedral flaky crystals. Muscovite (1 %) is both primary and secondary. Tourmaline, garnet, zircon and apatite are important accessories.

Fine- to Medium-grained Two Mica Granites, Locally Porphyritic (G-4)

The G-4 granite comprises several small separate intrusive stocks which occupy about 30 % of the surface exposures of the Kathu Plutons. It has been found to cross-cut the G-1, G-2, and G-3 throughout the area and usually it contains some inclusions of the G-1 and sedimentary rocks. The physiographic features of this granite are marked by low relief and gentle slope.

Megascopically, the G-4 granite is leucocratic (C.I. = 2.1–13.6 %). It is predominantly fine-grained allotriomorphic granular. The G-4 granite can be distinguished from the G-1 and G-2 granites by their widespread deuteric alteration. Mineralogically, quartz (29 %) and microcline usually perthitic (34 %), occur mostly as anhedral to subhedral grains. Plagioclase (23 %) is normally subhedral. Normal zoning is rather weak and the average anorthite content is An_{10}. Biotite (5 %) with reddish brown pleochroism occurs as subhedral flaky crystals and aggregates. Muscovite (up to 8 %), a very characteristic mineral of the G-4, usually occurs as flakes and in rare cases as radiated forms. Greisenization is a very important feature in some parts of the G-4. It is manifested by alteration of feldspar and biotite, by the development of abundant muscovite and chlorite, and by the formation of some characteristic accessories e.g., fluorite, tourmaline, garnet, and cassiterite. Such greisens are, therefore, probably formed by pneumatolytic alteration of late-phase granite in the apical zone of intrusion during the final stages of crystallization.

Fine-grained Mica Tourmaline Granites (G-5)

The G-5 granite occurs in a relatively very small amount, and seem to be the latest phase of crystallization. The rocks are typically light-gray coloured, mostly leucocratic (C.I. 5.1 %) and equigranular. Microscopically, this granite has nearly the same mineral composition as the G-4 but contains a larger amount of tourmaline.

GEOCHEMISTRY

The analytical data of major, minor, and trace elements of 24 granite samples together with CIPW norms, and some elemental ratios are presented in Tables 1 and 2. In Table 1 all volatile components are included in ignition loss (L.O.I.). In Table 2 additional analyses were made for few samples of the greisenized G-4 granites.

TABLE 1 (A)

MAJOR-OXIDE VALUES (WEIGHT %), AND C I P W NORMS OF BIOTITE GRANITE.

Type	G-1					G-2	
Sample No.	22–6–1	13–1–5	34–3–2	27–4–1	25–7–2	3–7–1	38–1–4
Major oxides							
SiO_2	69.55	70.53	66.98	68.54	69.45	70.98	67.37
TiO_2	0.53	0.51	0.61	0.59	0.54	0.35	0.52
Al_2O_3	15.31	14.77	16.32	15.27	15.02	14.12	16.55
Fe_2O_3	0.81	0.84	1.65	1.31	1.18	0.66	1.12
FeO	2.57	2.72	2.32	2.62	2.58	2.08	2.54
MnO	0.07	0.07	0.07	0.09	0.08	0.06	0.14
MgO	0.93	0.96	0.98	0.95	0.93	0.78	1.07
CaO	1.87	1.87	1.89	2.21	1.99	2.00	2.79
Na_2O	2.65	2.36	2.89	2.20	2.00	2.51	2.91
K_2O	4.42	4.26	4.67	3.50	3.80	4.41	3.95
P_2O_5	0.21	0.17	0.30	0.19	0.21	0.17	0.19
L.O.I.	1.01	1.64	1.19	1.62	1.67	1.25	0.80
Total	99.99	100.70	99.87	99.79	99.45	99.55	100.04
FeO (t)	3.64	3.73	4.20	4.19	4.01	2.95	3.91
K_2O/Na_2O	1.67	1.81	1.62	1.59	1.90	1.75	1.39
C I P W norms							
Q	30.64	33.89	26.38	30.51	33.83	32.68	26.25
or	26.16	25.04	27.82	22.59	23.26	26.15	23.93
ab	22.53	19.93	24.65	19.35	18.78	21.50	25.65
an	8.35	8.35	7.80	11.02	9.18	9.37	13.08
C	3.16	3.26	3.57	3.09	2.59	1.73	2.55
hy	5.61	6.10	4.26	5.31	5.21	4.91	5.74
ap	0.81	0.31	0.81	0.31	0.31	0.31	0.31
il	1.06	0.91	1.21	1.06	1.06	0.61	1.06
mt	1.14	1.14	2.51	1.83	1.83	0.91	1.60

TABLE 1 (B).

MAJOR-OXIDE VALUES (WEIGHT %), AND C I P W NORMS OF BIOTITE-MUSCOVITE GRANITE.

Type	G-4									
Sample No.	9–1–8	9–1–13	9–3–1	29–4–3	32–1–2	32–11–12	11–3–1*	10–4–1	31–7–1	26–5–2
Major oxides										
SiO_2	72.84	73.13	73.13	72.87	74.07	74.09	77.09	75.00	73.45	74.07
TiO_2	0.26	0.28	0.25	0.26	0.19	0.18	0.05	0.07	0.17	0.13
Al_2O_3	13.78	14.53	13.91	14.21	14.11	14.03	13.15	14.32	14.07	13.99
Fe_2O_3	0.37	0.31	0.26	0.32	0.09	0.30	0.03	0.12	0.15	0.14
FeO	1.74	1.50	1.36	1.37	1.00	0.84	0.55	0.48	1.01	0.80
MnO	0.07	0.03	u.d	0.03	u.d	0.05	0.08	0.10	0.03	0.04
MgO	0.45	0.48	0.50	0.48	0.40	0.25	0.11	0.11	0.27	0.18
CaO	0.81	0.80	1.25	0.90	1.06	0.88	0.58	0.66	1.17	0.99
N_2	2.43	2.58	3.66	2.54	2.69	2.86	2.47	2.83	2.90	2.61
K_2O	5.01	5.01	5.30	5.79	5.34	5.52	4.79	5.12	5.71	5.34
P_2O_5	0.14	0.12	0.14	0.10	0.08	0.05	0.09	0.12	0.08	0.14
L.O.I.	1.76	1.61	1.42	1.65	1.65	2.03	1.72	1.64	1.41	1.25
Total	99.66	100.37	101.18	101.52	100.68	101.08	100.71	100.57	100.42	99.54
FeO(t)	1.98	1.96	1.75	1.83	1.19	1.22	0.63	0.64	1.06	1.02
K_2O/Na_2O	2.06	1.94	1.45	2.78	1.98	1.93	1.93	1.81	2.47	2.06
C I P W norms										
Q	36.59	34.97	27.80	34.98	34.61	33.40	42.36	37.30	31.30	35.45
or	29.49	30.61	31.16	33.94	31.72	32.83	28.38	30.05	33.94	31.72
ab	20.45	22.03	30.94	21.50	22.55	24.12	20.98	24.12	24.65	22.03
an	3.06	3.06	5.29	3.62	5.01	4.45	2.78	2.50	5.01	5.01
C	3.26	3.57	2.20	2.45	2.04	1.73	2.85	3.16	1.22	2.04
hy	3.47	3.71	3.05	3.05	2.45	1.79	1.49	1.09	2.15	1.59
ap	0.31	0.31	0.31	0.31	0.31	–	0.31	0.31	–	0.31
il	0.46	0.61	0.45	0.46	0.30	0.30	–	0.15	0.30	0.30
mt	0.68	0.46	0.46	0.46	0.23	0.46	–	0.23	0.23	0.29

u.d. = undetectable, * = slightly greisenized

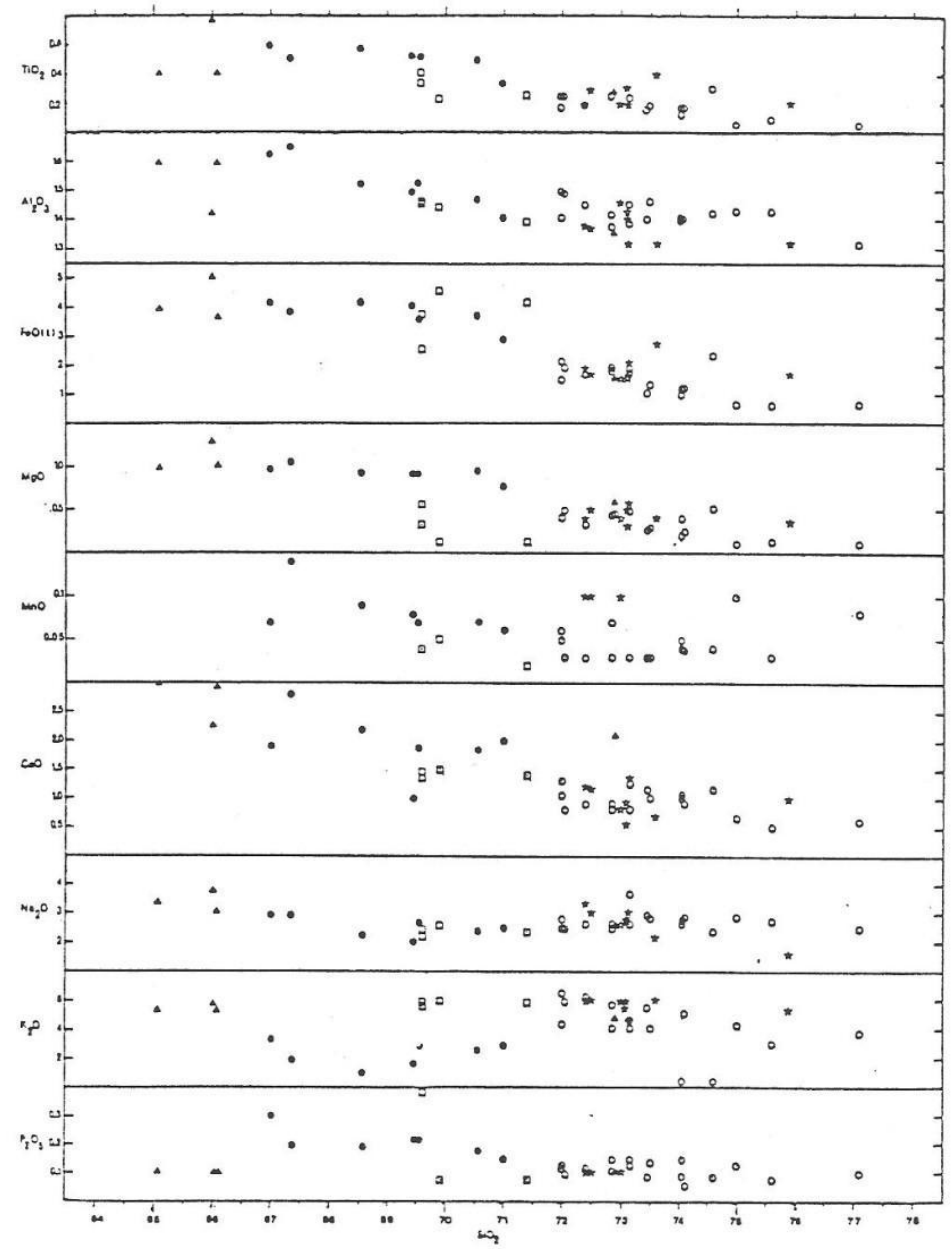
TABLE 1 (C)

MAJOR-OXIDE VALUES (WEIGHT %), AND C I P W NORMS OF BIOTITE-MUSCOVITE GRANITE.

Type	G-3					G-5	
Sample No.	26–9–1	31–8–1	26–2–2	33–6–1	19–5–2	35–5–1	38–1–6
Major oxides							
SiO_2	72.02	72.02	72.07	74.60	73.51	72.39	75.61
TiO_2	0.26	0.18	0.26	0.31	0.19	0.20	0.10
Al_2O_3	14.11	15.01	14.93	14.25	14.65	14.53	14.30
Fe_2O_3	0.37	0.36	1.28	0.49	0.23	0.20	0.05
FeO	1.60	1.02	0.62	1.70	1.04	1.35	0.48
MnO	0.06	0.05	0.03	0.04	0.03	0.03	0.03
MgO	0.42	0.43	0.33	0.51	0.30	0.34	0.14
CaO	1.06	1.32	0.81	1.17	0.99	0.92	0.50
Na_2O	2.43	2.77	2.46	2.36	2.81	2.61	2.72
K_2O	6.19	5.15	5.90	3.16	5.00	6.08	4.45
P_2O_5	0.11	0.12	0.09	0.08	0.13	0.11	0.07
L.O.I.	1.74	1.96	1.48	1.55	1.75	1.74	1.52
Total	100.37	100.39	100.26	100.22	100.63	100.50	99.97
FeO(t)	2.13	1.49	1.96	2.36	1.37	1.69	0.58
K_2O/Na_2O	2.55	1.86	2.40	1.34	1.78	2.33	1.64
C I P W norms							
Q	30.58	32.14	33.16	44.16	35.15	30.88	41.70
or	36.73	30.61	35.06	18.92	29.49	36.17	26.15
ab	20.45	23.60	20.98	19.93	23.59	22.03	23.07
an	4.45	5.84	3.06	5.84	4.45	3.62	2.50
C	1.73	2.65	3.26	4.79	3.57	2.35	4.08
hy	3.37	2.55	0.80	3.67	2.28	2.78	1.09
ap	0.31	0.31	0.31	–	0.31	0.31	–
il	0.46	0.30	0.46	0.60	0.30	0.46	0.15
mt	0.46	0.46	1.37	.068	0.23	0.23	–
he	–	–	0.14	–	–	–	–

Most rocks are high in SiO_2 content which tends to increase gradually from the G-1 to the G-5. Variation diagrams of major oxides against SiO_2 are shown in Figure 4. The biotite granites (G-1 and G-2) and the biotite-muscovite granites (G-3, G-4 and G-5) seem to define common variation trends. In general, TiO_2, Al_2O_3, FeO(t), MgO, CaO and P_2O_5 decrease slightly and continuously as SiO_2 content increases from the G-1 to the G-5. Na_2O and K_2O, on the contrary, tend to be uniform or slightly increase with increasing SiO_2 content. The AFM ($A = Na_2O + K_2O$, $F = FeO + 0.9Fe_2O_3 + MnO$, $M = MgO$) diagram as illustrated in Figure 5 shows variation trends from the less silicic granites of the G-1 and G-2 toward the more silicic granites of the G-3, G-4 and G-5 on the AF sideline.

The variation diagrams of trace elements versus SiO_2 illustrate similarity in trend when the composition moves from the biotite granites towards the biotite-muscovite



▲ Adamellites (Garson et al., 1975) ★ Biotite granites (Garson et al., 1975) ● Biotite granites

□ Granites (Suensilpong & Putthapiban, 1979) ☆ Biotite-muscovite granites (Garson et al., 1975) ○ Biotite-muscovite granites

Fig. 4. Variation diagram of other oxides (weight %) versus SiO_2 (weight %) for granites of Phuket Island.

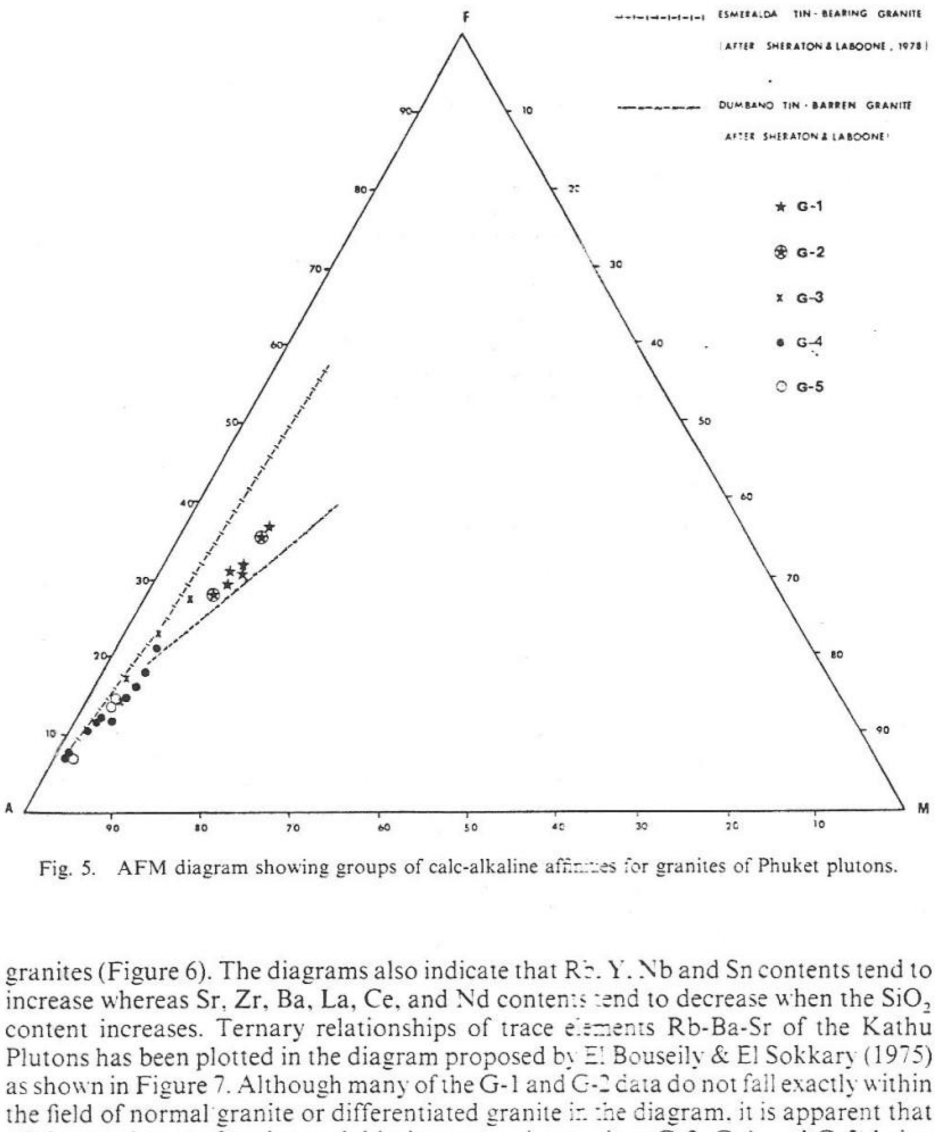


Fig. 5. AFM diagram showing groups of calc-alkaline affinities for granites of Phuket plutons.

granites (Figure 6). The diagrams also indicate that Rb, Y, Nb and Sn contents tend to increase whereas Sr, Zr, Ba, La, Ce, and Nd contents tend to decrease when the SiO_2 content increases. Ternary relationships of trace elements Rb-Ba-Sr of the Kathu Plutons has been plotted in the diagram proposed by El Bouseily & El Sokkary (1975) as shown in Figure 7. Although many of the G-1 and G-2 data do not fall exactly within the field of normal granite or differentiated granite in the diagram, it is apparent that all the granites are fractionated, biotite-muscovite granites (G-3, G-4, and G-5) being more differentiated. Since greisens are hydrothermally altered, they should not be considered with others.

TIN-BEARING GRANITES AND TIN-BARREN GRANITES: A DISCUSSION

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

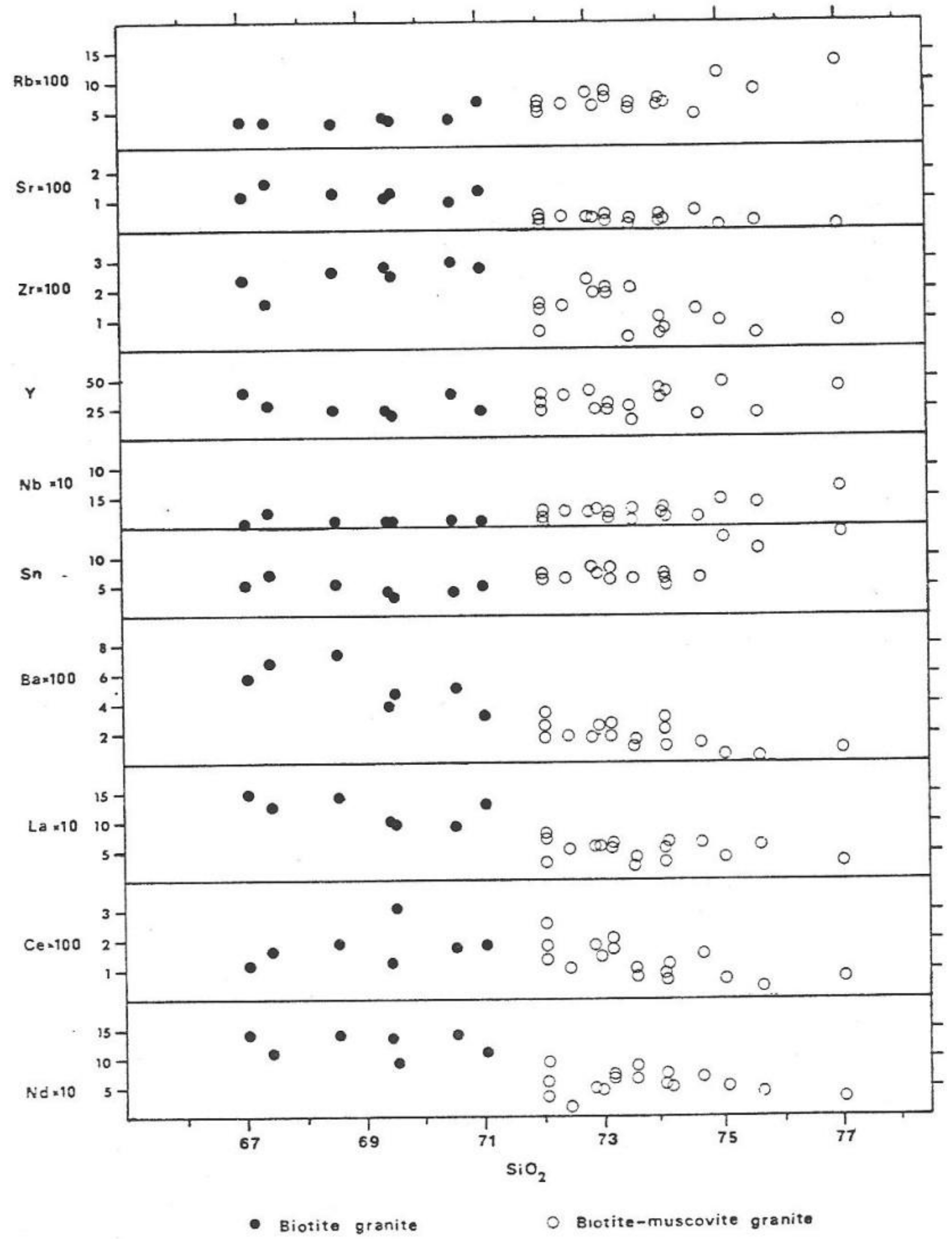


Fig. 6. Variation diagram of trace elements (ppm) versus SiO_2 (weight %) for granites.

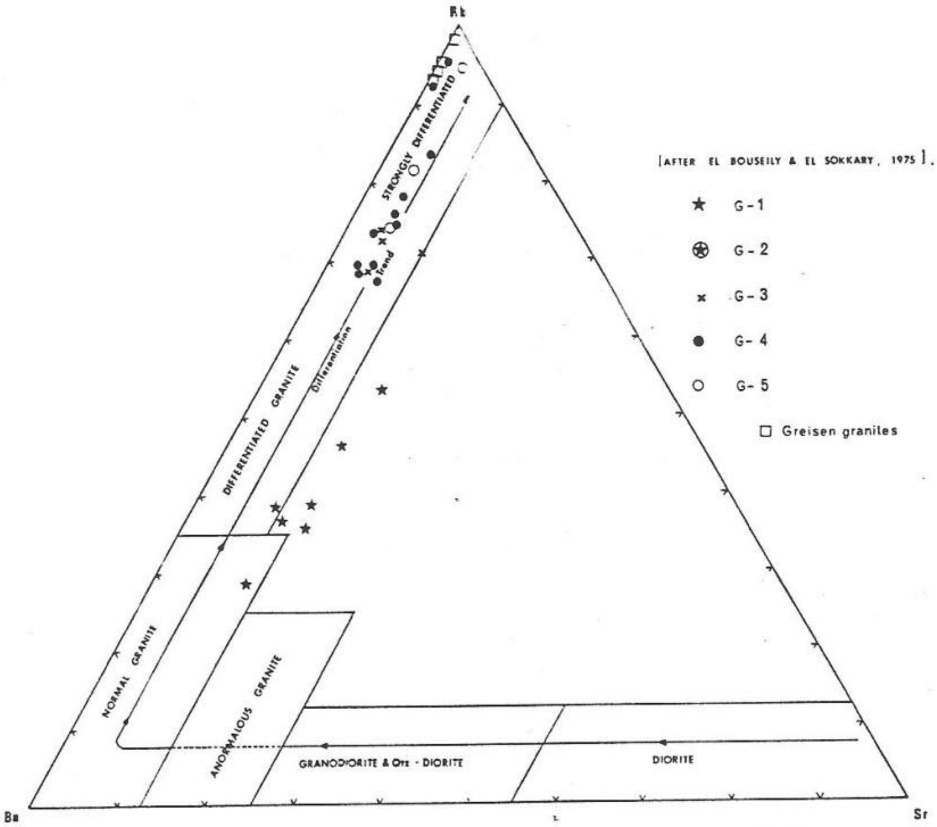


Fig. 7. Rb-Ba-Sr variation diagram [after El Bouseily & El Sokkary, 1975].

superimposed lode tin deposits may occur within it. When applying the terms "tin-bearing and tin-barren" to granites of Kathu Plutons, data presented in Table 2 indicate that there is no significant difference in the Sn contents (ppm) between the biotite granites and biotite-muscovite granites. However, the greisenized parts are exceptionally high in Sn content.

Temporal and Spatial Aspects

Evidences from many countries have suggested that in a given tin field the strongest primary mineralization occurs spatially within, or in the vicinity of clearly defined steep-sided cupolas (Hosking, 1971; Tauson & Kozlov, 1973; Groves and McCarthy, 1978). Moreover, in areas where there are more than one phase of granites in the given plutons, the later phases seem to be richer in tin than the earlier phases (Aranyakanon, 1961; Groves and Taylor, 1973; Sminova, 1974; Lugov, 1978; Sheraton & Labonne, 1978; and Beckinsale, 1979). Similar temporal and spatial relationships hold for the tin mineralization in the granites of Kathu Plutons.

TABLE 2 (A)

TRACE-ELEMENT CONCENTRATIONS (PPM) AND
ELEMENTAL RATIOS OF BIOTITE GRANITE.

Type	G-1					G-2	
Sample No.	22–6–1	13–1–5	34–3–2	27–4–1	25–7–2	3–7–1	38–1–4
Trace-elements							
Rb	443	405	401	338	383	529	470
Sr	118	95	118	124	128	138	184
Zr	280	306	231	273	250	289	149
Y	24	33	33	25	19	21	28
Nb	11	13	4	10	5	7	22
Sn	4	4	5	5	3	5	7
Ba	389	553	581	720	475	323	674
La	103	90	145	140	89	132	124
Ce	117	172	109	183	303	176	157
Nd	134	134	132	136	88	103	106
Sm	27	8	3	22	19	10	10
Sb	–	–	3	3	–	2.5	–
Elemental ratios							
Rb/Sr	4	4	3	3	3	4	3
K/Rb	83	88	78	87	83	70	72
K/Ba	95	65	54	41	67	115	50
Ba/Sr	3	6	5	6	4	2	4
Ba/Rb	0.9	1.4	1.4	2.1	1.2	0.6	1.4
Ca/Sr	134	141	114	127	111	104	108
Ca/Y	558	406	409	632	747	680	711

Petrological Aspects

The D.I. (differentiation index) and the P.I. (petrological index) were used by Flinter *et al.* (1972) and Smith and Turek (1976), respectively, for grouping the granites as either tin-bearing or tin-barren granitic rocks. Flinter *et al.* (1972) concluded that tin-mineralization occurs in granites of New England, Australia where D.I. is over 85. Smith and Turek suggested that the granites in Nova Scotia, East Canada which are most likely to be tin-bearing have P.I. less than 4. The G-3, G-4, and G-5 granites mostly have D.I. more than 85 and P.I. nearly 4 whereas the G-1 and G-2 have lower D.I. and higher P.I.

Geochemical Aspects

Figure 8 shows a ternary plots of SiO_2 – (CaO + MgO + FeO) – (Na_2O + K_2O + Al_2O_3) for granites of Kathu Plutons compared with the New England granites. The diagram clearly shows the distinction between the more silicic granites (G-3, G-4, G-5) and the less silicic granites (G-1 and G-2).

Trace elements offer some of the most reliable criteria for differentiating between a

TABLE 2 (B)

TRACE-ELEMENT CONCENTRATIONS (PPM) AND ELEMENTAL RATIOS OF BIOTITE-MUSCOVITE GRANITE.

Type	G-4										
Sample No.	9-1-18	9-1-13	9-3-1	29-4-3	32-1-2	32-11-12	11-3-11	15-3-2	31-7-12	6-5-21	9-2-1
Trace-elements											
Rb	815	786	704	633	727	652	1370	1141	655	666	626
Sr	45	48	37	47	34	43	11	16	40	38	65
Zr	238	205	199	194	54	103	90	99	209	85	339
Y	39	28	23	25	35	43	44	46	15	41	50
Nb	22	14	20	28	26	23	64	44	31	19	29
Sn	8	6	8	7	6	7	19	13	6	5	7
Ba	184	185	275	233	229	263	84	51	169	95	240
La	56	54	60	57	51	26	29	33	37	61	132
Ce	172	157	198	134	75	63	59	55	67	114	140
Nd	37	70	70	41	69	48	25	44	60	42	28
Sm	11	7	24	6	5	13	1	10	22	3	19
Sb	2	2	1	3	2	4	1	4	2	6	2
Elemental ratios											
Rb/Sr	18	18	19	13	21	15	124	71	16	18	10
K/Rb	52	49	63	77	62	71	29	38	73	67	–
K/Ba	229	229	162	209	196	176	479	843	284	42.7	–
Ba/Sr	4	4	7	5	7	6	8	3	4	3	4
Ba/Rb	0.2	0.2	0.4	0.4	0.3	0.4	0.1	0.1	0.3	0.1	0.4
Ca/Sr	129	119	240	136	224	147	372	293	209	187	–
Ca/Y	149	204	386	256	217	147	93	102	558	173	–

TABLE 2 (C)

TRACE-ELEMENT CONCENTRATIONS (PPM) AND ELEMENTAL RATIOS OF BIOTITE-MUSCOVITE GRANITE AND GREISENIZED GRANITE.

Type	G-3				G-5			Greisenized G-4			
Sample No.	26-9-1	31-8-1	26-2-2	33-6-1	19-5-1	35-5-1	38-1-6	Rang* 1	11-5*-1	Kao* 1	Kao* 2
Trace-elements											
Rb	662	681	587	469	670	680	904	1395	1134	2574	2602
Sr	43	32	37	67	32	44	29	9	1	1	1
Zr	158	60	140	134	41	157	46	174	134	61	273
Y	29	43	22	20	27	38	19	47	62	110	96
Nb	11	25	17	12	8	28	38	35	25	105	99
Sn	6	7	6	6	6	6	11	23	29	124	125
Ba	264	219	188	127	121	193	21	78	85	50	38
La	27	74	78	62	24	49	54	44	31	37	24
Ce	245	121	163	141	98	94	32	134	66	20	u.d
Nd	25	50	87	62	80	10	35	13	25	u.d	38
Sm	8	10	16	9	32	2	9	24	10	10	12
Sb	2	2	–	1	2	2	2	1	2	2	1
Element ratios											
Rb/Sr	15	21	16	7	21	15	31	174	1134	2574	2606
K/Rb	79	64	84	57	63	75	41	–	–	–	–
K/Ba	197	198	264	209	347	265	1780	–	–	–	–
Ba/Sr	6	6	7	5	4	4	0.7	10	85	50	38
Ba/Rb	0.4	0.4	0.3	0.3	0.2	0.3	0.2	0.1	0.1	0.02	0.01
Ca/Sr	177	294	157	125	222	150	124	–	–	–	–
Ca/Y	262	219	264	420	263	174	189	–	–	–	–

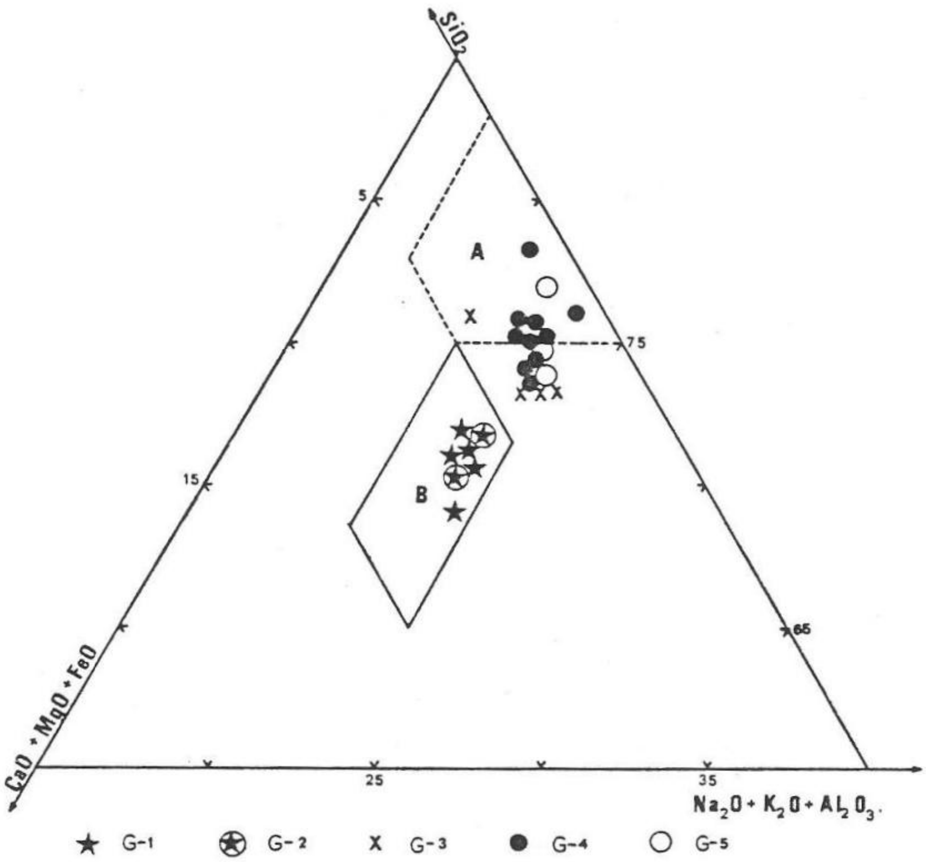


Fig. 8. Ternary system $SiO_2 - [CaO + MgO + FeO] - [Na_2O + K_2O + Al_2O_3]$ for granites of Phuket plutons compared with [A] tin-bearing and [B] tin-barren New England granites [Juniper Kleeman, 1979].

potential tin-bearing granite and one that is not (Tauson & Kozlov, 1973). Table 2 illustrates that G-3, G-4, and G-5 granites have much higher Ca/Sr ratio and can be differentiated from those of G-1 and G-2 granites. Figure 9 shows that G-3, G-4, and G-5 have lower abundances of Ca and Sr compared with G-1 and G-2. The Ba/Rb ratio has been recommended by Tauson & Kozlov (1973) as the best indicator of mineralization. Ratio of less than 1 is generally confined to late-stage highly fractionated granites that are frequently accompanied by tin deposits. The G-3, G-4, and G-5 granites show Ba/Rb ratio much less than 1 (Table 2 b & c).

If the chemical analyses of the granites of the Kathu Plutons are only considered, there appears to exist a compositional gap betwen the biotite granites (G-1 & G-2) and the biotite-muscovite granites (G-3, G-4, and G-5) at approximately 71.5% SiO_2.

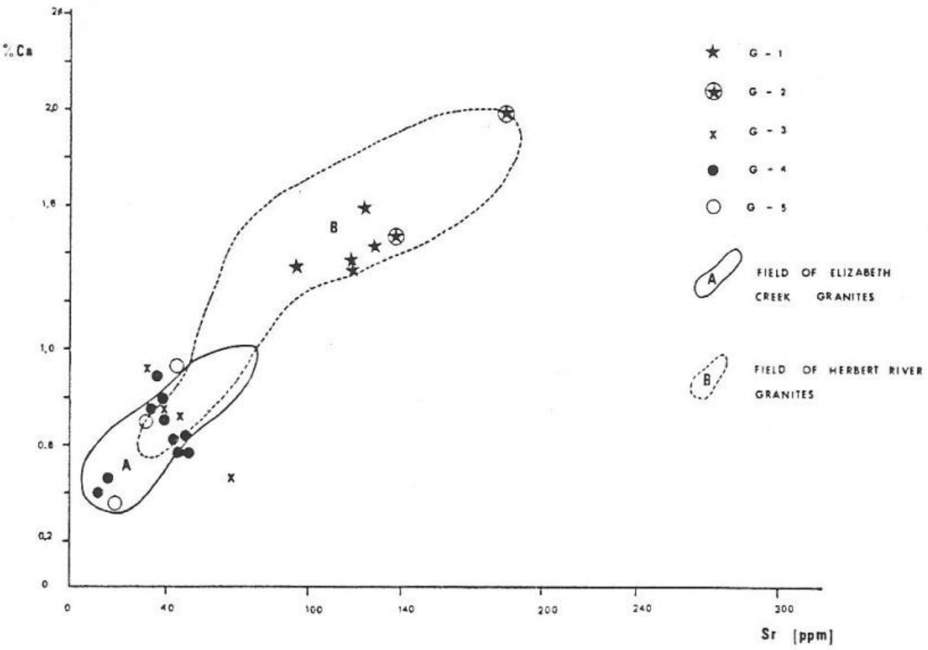


Fig. 9. Plot of Ca against Sr of granites of Phuket plutons compared with Elizabeth Creek granites and Herbert River granites (Sheraton & Labonne, 1978).

However, when other additional data (Garson *et al.*, 1975; Suensilpong and Putthapiban, 1979) of granitic rocks from Phuket and the mainland are taken into account as shown in the variation diagram of Figure 4, the gap disappears. The high proportion of the volume of the exposed biotite granite over the hornblende-biotite adamellite and biotite-muscovite granite in Phuket island and adjacent areas could imply that the composition of parental magma lies close to the composition of average biotite granite. The relatively small amount of hornblende-biotite adamellite is possibly the earliest differentiated phase of the parental magma. The biotite granite G-1 and G-2 is the main phase and the biotite-muscovite granite G-3, G-4, and G-5 represents the ultimate residual liquid of fractional crystallization. Tin-concentrating in the biotite-muscovite granite is the result of partitioning of tin in the very late residual liquid magma. However, the increment of the tin including niobium in the biotite-muscovite granite was still not sufficient enough to form tin ores in the rocks. The tin was further concentrated in the very final magmatic phases of pegmatites, aplites and also in the granites through greisenization. Therefore, the compositional differences between the so-called tin-bearing and tin-barren granites are not fundamental characteristics of magmas but merely the consequences of fractionation processes.

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