CHAPTER VII

GEOCHEMISTRY

7.1 Introduction

A great care was taken to select fresh specimens for analyses that were reasonably representative. The details of sampling techniques and analytical procedures were discussed in the method of investigation (Section 1.6). The analytical data together with CIPW norms, differentiation index (D.I.) and some elemental ratios are present in Table 2 and 3. All major-oxide concentrations are given in weight percentage and trace element concentrations in part per million (ppm). The differentiation index is calculated from the sum of normative quartz, orthoclase and albite, corrected to 100 percent. The whole rock-analytical data from the Phuket Plutons have previously reported by several workers (Pitakpaiwan, 1969; Garson, et al., 1975: Suensilpong and Putthapiban, 1978).

Silica variation diagrams for major oxides and some trace elements are shown in Figure 8 to 19. The ranges and averages of these major oxides and trace elements are summerized in Table 4(a) and 4(b) in order to provide a comparision with the average compositions of granites from many parts of the world (Table 5 and 6). The variation diagrams of the major-oxides and trace elements versus SiO_2 do not show the significant difference among the granite suites. Some trends of oxides and trace elements are also compared with those of Mesozoic Fang tin-bearing and-barren granites, northern Thailand (Boom, et al., 1979) and of Mesozoic Benom tin-bearing and-barren granites, western Malaysia (Ahmad, 1979). Hosking (1 979) noted that these granites of Fang, Benom and Phuket Plutons are located in the same tin belt (i.e. western tin belt of S.E. Asia). Broadly speaking the chemical results as shown in many figures and tables reveal that the granite types of Phuket Plutons can be simply grouped into the more silicic and less silicic groups depending mainly on the silica contents (Figure 5) and the D.I. (Figure 25 C).

Key to Table 2 to 4

G-1 = coarse-grained porphyritic biotite granites

G-2 = fine - to medium-grained biotite granites

G-3 = medium - to coarse-grained biotite-muscovite granites, slightly porphyritic

G-4 = fine - to medium-grained biotite-muscovite granites, locally porphyritic

G-5 = fine-grained biotite-muscovite-tourmaline granites

Q = normative quartz

or = normative orthoclase

ab = normative albite

an = normative anorthite, ap = normative apatite

C = normative corrundum, il = normative ilmenite

hy = normative hypersthene, mt = normative magnetite

Table 2 (a). Major-oxide values (weight %), C I P W norms and differentiation Index (D.I) of granites of Phuket Plutons

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	68.55	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
Tot.	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
D.I.	80.17	79.71	79.80	26.21	78.74	81.42	75.46

Table 2 (b). Major-oxide values (weight %), C I P W norms and differentiation Index (D.I) of granites of Phuket Plutons

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	14.09	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
Na_2O	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
Tot.	99.66	100.37	101.18	101.52	100.68	101.08	100.71	100.57	100.42	99.54
Feo(t)	1.93	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	-
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
D.I	88.09	86.67	90.21	96.61	89.58	91.19	92.80	92.42	90.50	90.62

u.d. = undetectable, * = slightly greisseniged

Table 2 (c). Major-oxide values (weight %), C I P W norms and differentiation Index (D.I.) of granites of Phuket Plutons

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
Tot.	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	0.68	0.23	0.23	-
he	-	-	0.14	-	-	-	-
D.I.	89.06	87.70	90.47	84.2	89.2	90.13	92.08

Table 3 (a). Trace-element concentrations (ppm) and elemental ratios of granites of Phuket Plutons

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
Sh	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
Na	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

Table 3 (b). Trace-element concentrations (ppm) and elemental ratios of granites of Phuket Plutons

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	6-5-2	19-2-1
Trace-elements											
Rb	815	186	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	399
Y	39	28	23	25	35	43	44	46	15	41	50
Nb	22	14	20	28	26	23	64	44	31	19	29
Sh	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 3 (c). Trace-element concentrations (ppm) and elemental ratios of granites of Phuket Plutons

Type	G - 3				G - 5			greisen granites			
Sample No.	26-9-1	31-8-1	26-2-2	33-6-1	19-5-2	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	2606
Sr	43	32	37	67	32	44	29	8	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	-	-	-	-

Table 4a Ranges and averages of major-oxide concentration (weight %) of granites of Phuket Pluton

	G - 1		G - 2		G - 3		G - 4		G - 5	
	range	av.	range	av.	range	av.	range	av.	range	av.
SiO_2	66.98-70.13	69.01	67.37-70.98	69.18	72.02-74.60	72.68	72.84-77.09	73.97	72.39-75.60	73.80
TiO_2	0.51- 0.61	0.56	0.35- 0.52	0.43	0.18- 0.31	0.25	0.05- 0.28	0.18	0.10- 0.20	0.16
Al_2O_3	14.77-16.32	15.34	14.12-16.55	15.33	14.11-15.01	14.57	13.15-14.53	14.00	14.30-14.55	14.49
Fe_2O_3	0.81- 1.65	1.16	0.66- 1.12	0.89	0.37- 1.28	0.63	0.03- 0.32	0.20	0.05- 0.23	0.16
FeO	2.[illegible]- 2.72	2.56	2.08- 2.54	2.31	0.62- 1.70	1.24	0.48- 1.74	1.06	0.48- 1.35	0.95
MnO	0.07- 0.09	0.08	0.06- 0.14	0.13	0.03- 0.06	0.05	0.00- 0.10	0.04	0.03	0.30
MgO	0.93- 0.96	0.95	0.78- 1.07	0.93	0.33- 0.51	0.42	0.11- 0.50	0.32	0.14- 0.34	0.26
CaO	1.87- 2.21	1.97	2.00- 2.79	2.40	0.81- 1.71	1.09	0.58- 1.25	0.91	0.50- 0.99	0.80
Na_2O	2.[illegible]- 2.89	2.42	2.51- 2.91	2.71	2.36- 2.77	2.51	2.43- 3.66	2.71	2.61- 2.81	2.71
K_2O	3.50- 4.67	4.13	4.04- 4.41	4.23	3.16- 6.19	5.10	4.79- 5.79	5.30	4.45- 6.08	5.18
P_2O_5	0.17- 0.30	0.22	0.17- 0.19	0.18	0.08- 0.12	0.10	0.05- 0.14	0.11	0.07- 0.13	0.10
L.O.I	1.01- 1.80	1.43	0.80- 1.25	1.03	1.45- 1.95	1.67	1.41- 2.03	1.65	1.50- 1.75	1.67
D.I.	76.21-80.17	78.93	75.46-81.42	78.44	84.20-90.47	87.86	86.67-96.61	90.87	89.20-92.08	90.47
No. of sample	5		2		4		10		3	

Table 4b Ranges and averages of trace-element concentrations (ppm) of types of granites of Phuket Plutons

Type	G - 1		G - 2		G - 3		G - 4		G - 5		greisen granite	
	range	av.	range	av.	range	av.	range	av.	range	av.	range	av.
Rb	338-443	393.0	470-529	499.5	469-681	600.0	633-1370	788.6	670-904	751.0	1134-2606	1927.2
Sr	95-128	116.6	138-184	161.0	32- 67	47.7	11- 65	38.5	29- 44	35.0	1- 8	2.8
Zr	231-306	268.0	149-289	219.0	60-158	123.0	45- 339	170.5	41-157	81.0	61- 273	160.5
Y	19- 33	26.8	21- 28	24.5	20- 43	28.5	15- 50	35.4	19- 38	28.0	47- 110	78.8
Nb	4- 13	8.6	7- 22	14.5	11- 25	16.2	14- 64	29.0	8- 38	24.7	25- 105	65.5
Sn	3- 5	4.2	5- 7	6.0	6- 7	6.3	5- 19	8.4	6 6	6.0	23- 125	75.2
Ba	389-720	543.6	323-674	498.5	127-264	119.5	51- 275	182.5	21-193	111.3	38- 85	62.8
La	89-140	113.4	124-132	128.0	27- 78	60.0	26- 132	54.2	24- 54	42.0	24- 44	34.0
Ce	109-303	188.8	157-176	166.5	121-254	167.5	55- 198	111.9	32- 98	74.7	0- 134	55.0
Na	88-136	98.4	103-106	104.5	25- 87	56.0	25- 70	48.5	10- 80	41.7	0- 25	9.5
Sm	3- 27	15.8	10	10.0	8- 16	10.8	1- 24	11.1	2-33	14.7	10- 24	14.0
Sb	0- 3	1.6	0-2.5	1.2	0- 1	1.3	1- 6	2.6	2	2.0	1- 2	1.5
No.*	5		2		4		11		3		4	

No.* = number of samples

Table 5 Average major oxide values (in weight percent) of some granitic rocks.

Source	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
1	71.21	0.42	14.70	-	3.24*	0.05	0.55	2.00	3.54	4.18	0.16
2	73.10	0.21	13.96	0.91	1.44	0.05	0.55	1.21	3.01	4.58	0.20
3	71.39	0.26	15.44	0.30	1.33	0.04	1.13	1.44	3.30	4.04	0.33
4	71.53	0.26	13.70	1.02	2.01	0.06	0.36	1.37	3.42	4.75	0.15
5	69.69	0.63	14.30	3.13*1	-	0.05	1.59	1.34	2.09	4.79	0.13
6	74.67	0.12	13.90	0.49*1	-	0.01	0.23	0.17	3.38	5.17	0.04
7	70.31	0.42	14.46	0.88	1.97	0.05	0.93	1.81	3.24	4.42	0.17
8	75.60	0.13	12.96	0.38	1.22	0.03	0.31	0.35	3.61	4.62	0.04
9	72.83	0.27	13.43	0.65	1.88	0.04	0.53	1.83	2,98	4.92	0.11
10	71.80	0.32	13.82	0.70	1.90	0.05	0.83	2.25	3.43	3.91	0.07
11	75.40	0.15	12.89	0.32	1.17	0.04	0.19	0.87	3.53	4.63	0.05
12	70.74	0.15	16.41	0.49	0.76	0.05	0.72	1.01	3.36	4.19	0.24
13	72.08	0.29	14.25	0.45	1.49	0.06	0.46	1.17	3.11	5.09	0.25
14	73.55	0.09	14.43	0.85	0.67	0.02	0.38	0.70	3.77	4.46	0.42
15	75.73	0.02	13.63	0.24	0.56	0.11	0.19	0.63	3.47	4.70	0.00
16	74.36	0.20	13.63	1.16	0.95	0.04	0.41	1.07	3.40	3.90	0.18
17	72.65	0.10	13.92	0.59	1.08	0.04	0.20	0.65	3.12	4.45	0.27
18	72.45	0.51	12.32	1.64	1.86	0.05	0.66	1.31	3.67	4.61	0.11

* Total iron as FeO ; *1 Total iron as Fe_2O_3

Sources are in page 90, 91

Table 6 Average trace-element values (in ppm)

of some granitic rocks

Source	Rb	Sr	Zr	Y	Sn	Ba	Cs	La
1	145	285	180	40	3	600	57	55
2	440	70	140	n.d	22	175	n.d	n.d
3	n.d	200	n.d	n.d	400	500	n.d	n.d
5	340	79	172	30	33	728	n.d	126
6	494	56	72	27	30.7	326	n.d	101
7	284	166	167	109	6	640	n.d	27
8	585	20	67	184	27	54	n.d	8
10	219	124	142	42	4	420	64	36
11	404	42	125	76	7	174	69	41
15	388	42	88	26	4	270	n.d	30
16	314	57	n.d	n.d	16	180	n.d	n.d
17	645	27	59	n.d	35	71	n.d	n.d
18	305	20	107	26	4	107	n.d	15

n.d = Not determined

Sources are in page 90, 91

Sources of Table 5 and Table 6

1. Average granite (Taylor, 1968)
2. Average of 185 tin-bearing granites (Stemprok and Skvor, 1974)
3. Average of 6 two-mica granites of Khuntan Batholith, N Thailand (Suensilpong et al., 1977)
4. Average of 15 Quartz monzonites of Tak Granites, N, Thailand (Pongsapitch and Mahawat, 1977)
5. Average of 12 Fang tin-barren granites, N Thailand (Boom et al., 1979)
6. Average of 15 Fang tin- bearing granites, N Thailand (Boom et al., 1979)
7. Average of 5 Benom tin-barren granites, W Malaysia (Ahmad, 1979)
8. Average of 6 Benom tin bearing granites, W Malaysia (Ahmad 1979)
9. Average of 8 tin-bearing granites, Indonesia (Stemprok and Skvor, 1974)
10. Average of 106 tin-barren granites, NE Queensland (Sheraton and Labonne, 1978)
11. Average of 140 tin- bearing granites, NE Queensland (Sheraton and Labonne, 1978)
12. Average of 41 tin-bearing granites of Bretagne Plateau France (Stemprok and Skvor, 1974)

13. Average of 25 tin-bearing granites of Cornwall, England (Stemprok and Skvor, 1974)

14. Average of 15 tin- bearing granites of Erzgebirge,GDR (Stemprok and Skvor,. 1974)

15. Average of 3 tin-bearing granites of Alaska, USA (Stemprok and Skvor, 1974) (major oxides)

    Average of 8 tin-bearing granites of Snowy Mts., Australia (Klobe and Taylor,1966) (trace elements)

16. Average of 69 tin-bearing granites of Central Kazakstan, USSR (Stemprok and Skvor, 1974) (major oxides)

    Average of 31 tin-bearing granites of Central Kazakstan, USSR (Kozlov, 1974) (trace elements)

17. Average of 144 tin-bearing granites of Czechoslovakia (Stemprok and Skvor, 1974) (major oxides)

    Average of 70 tin-bearing granites of Czechoslovakia (Klominsky and Absolonova, 1974) (trace elements)

18. Average of 12 tin-bearing granites of S Africa (Stemprok and Skvor, 1974) (major oxides)

    Average of 8 tin-bearing granites of S Africa (Klobe, 1966) (trace elements)

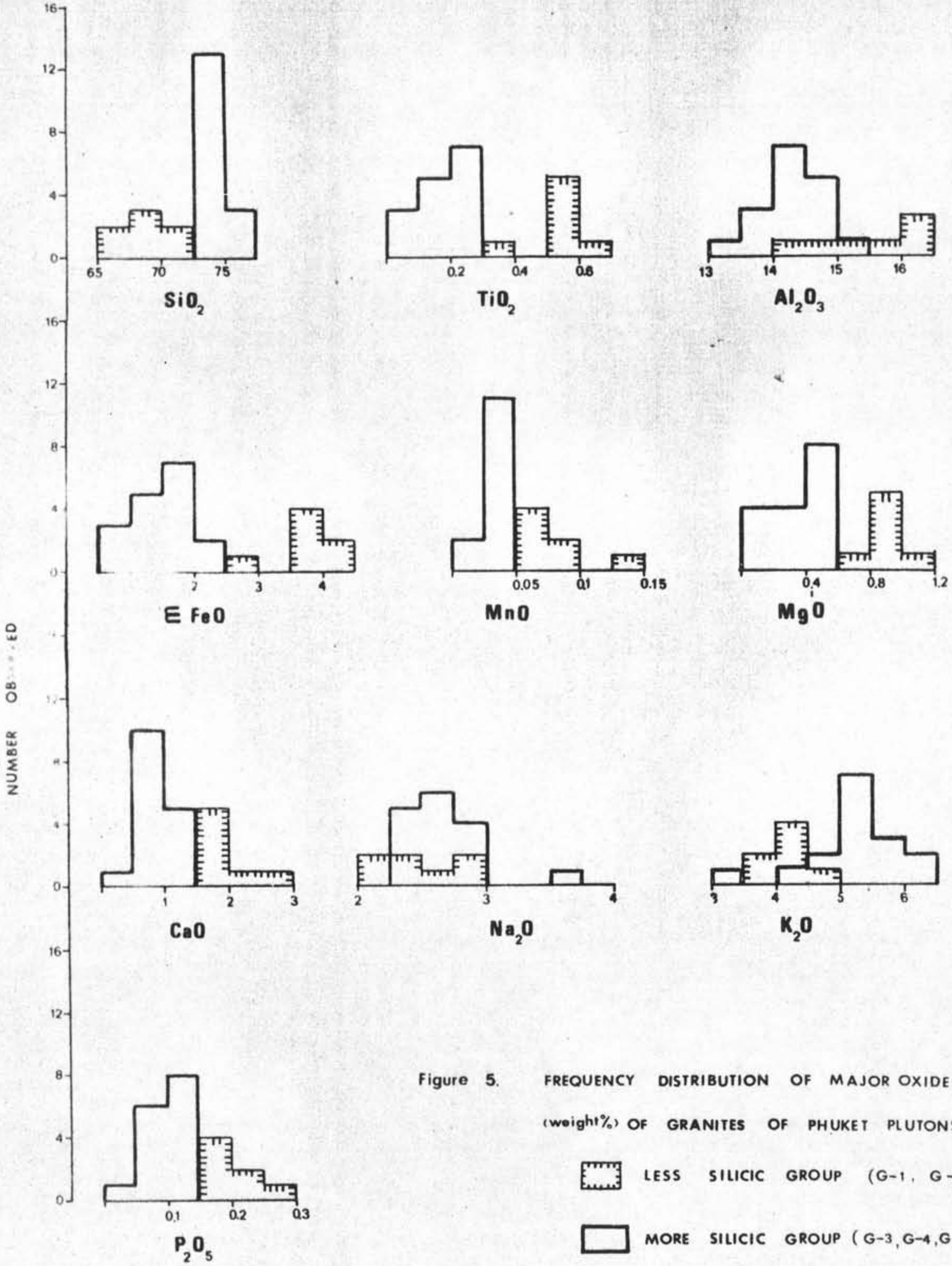
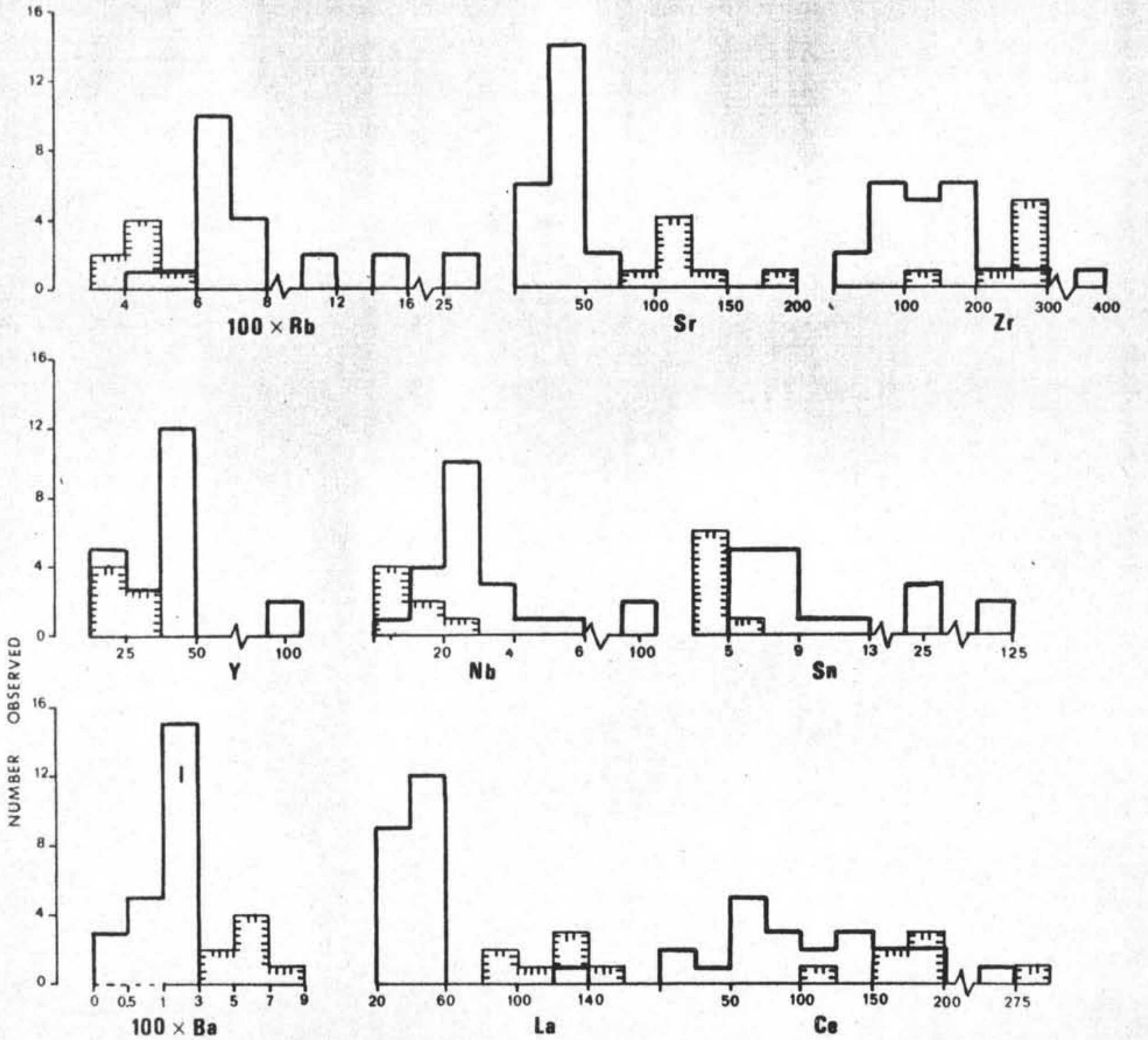


Figure 5. FREQUENCY DISTRIBUTION OF MAJOR OXIDES (weight%) OF GRANITES OF PHUKET PLUTONS.

LESS SILICIC GROUP (G-1, G-2)

MORE SILICIC GROUP (G-3, G-4, G-5, AND HIGHLY GREISENIZED GRANITES)



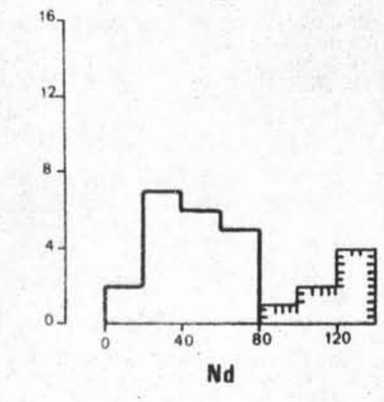


Figure 6. FREQUENCY DISTRIBUTION OF TRACE ELEMENTS (ppm.) OF GRANITES OF PHUKET PLUTONS.

LESS SILICIC GROUP (G-1 . G-2)

MORE SILICIC GROUP (G-3, G-4, G-5 AND HIGHLY GREISENIZED GRANITES)

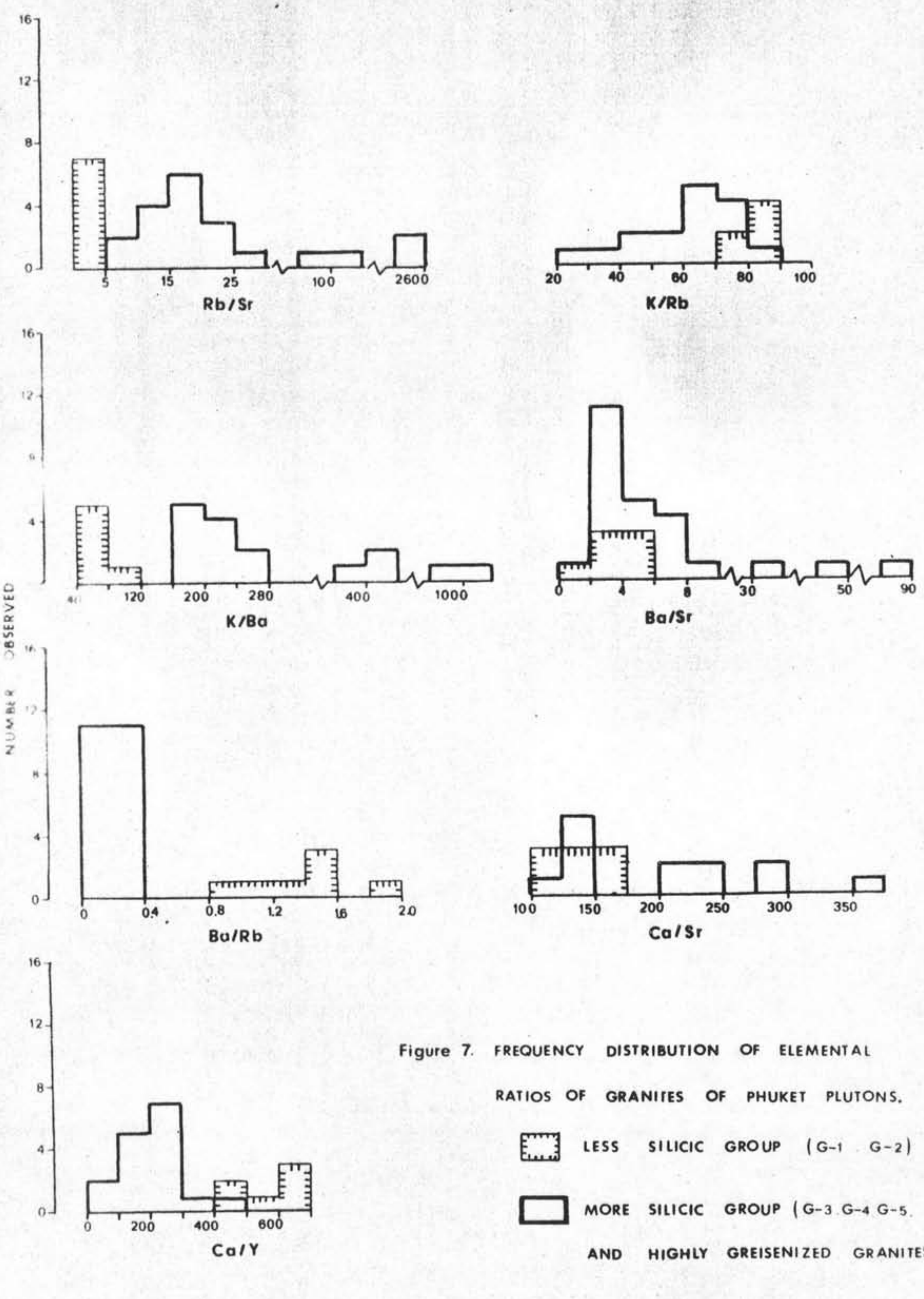


Figure 7. FREQUENCY DISTRIBUTION OF ELEMENTAL RATIOS OF GRANITES OF PHUKET PLUTONS.

LESS SILICIC GROUP (G-1 G-2)

MORE SILICIC GROUP (G-3 G-4 G-5 AND HIGHLY GREISENIZED GRANITES)

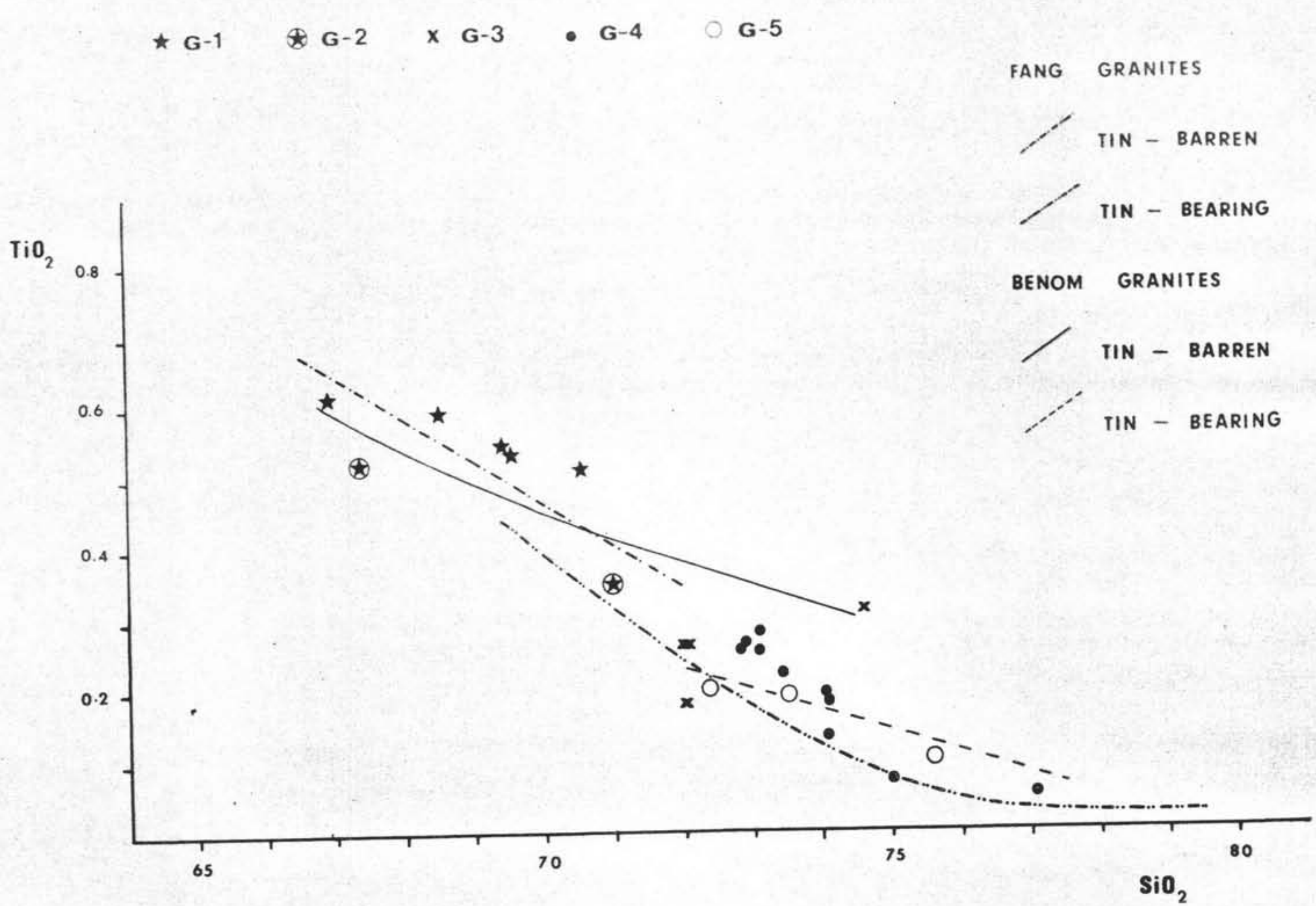


FIGURE 8. VARIATION OF TiO_2 AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

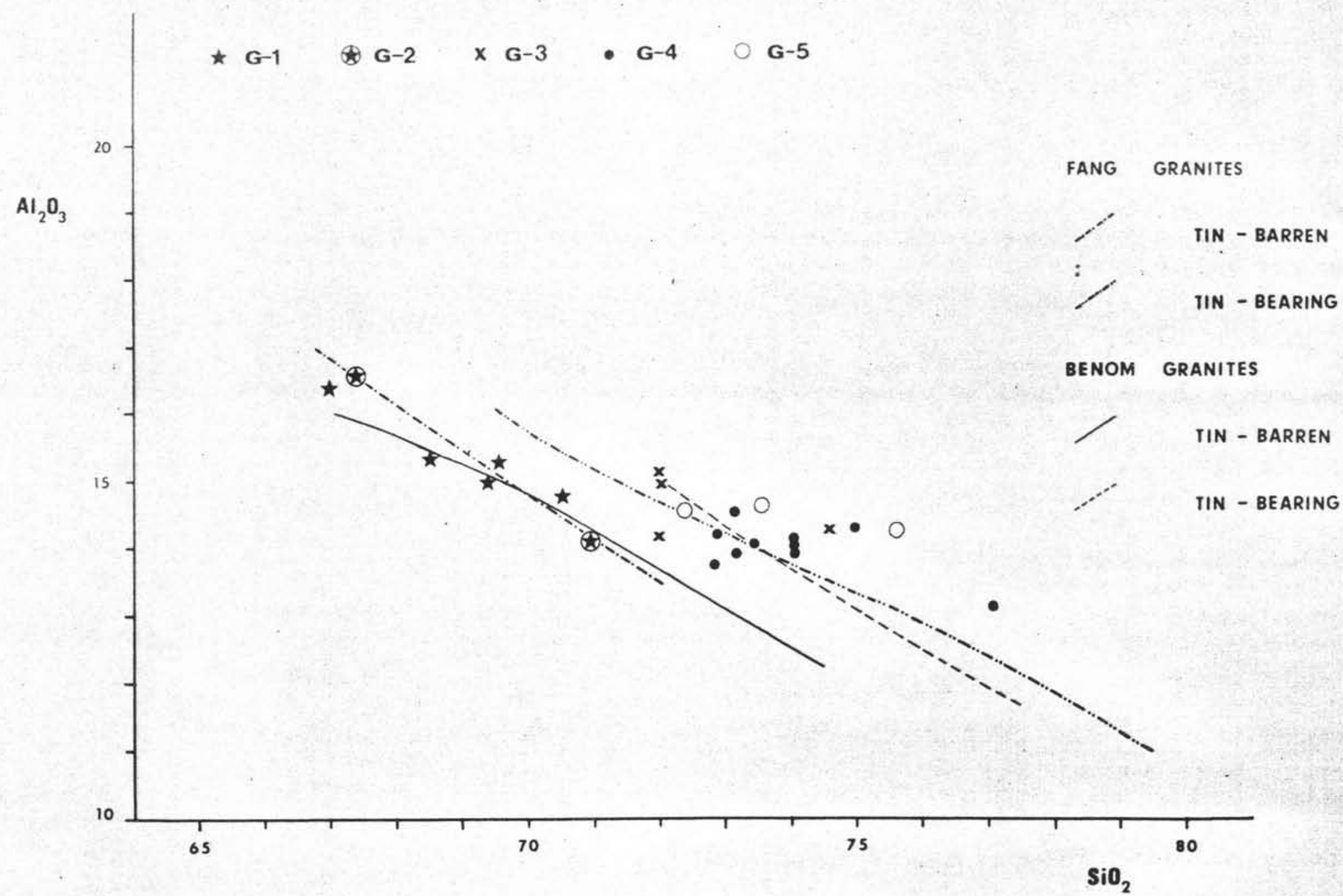


FIGURE 9 VARIATION OF Al_2O_3 AGIANST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

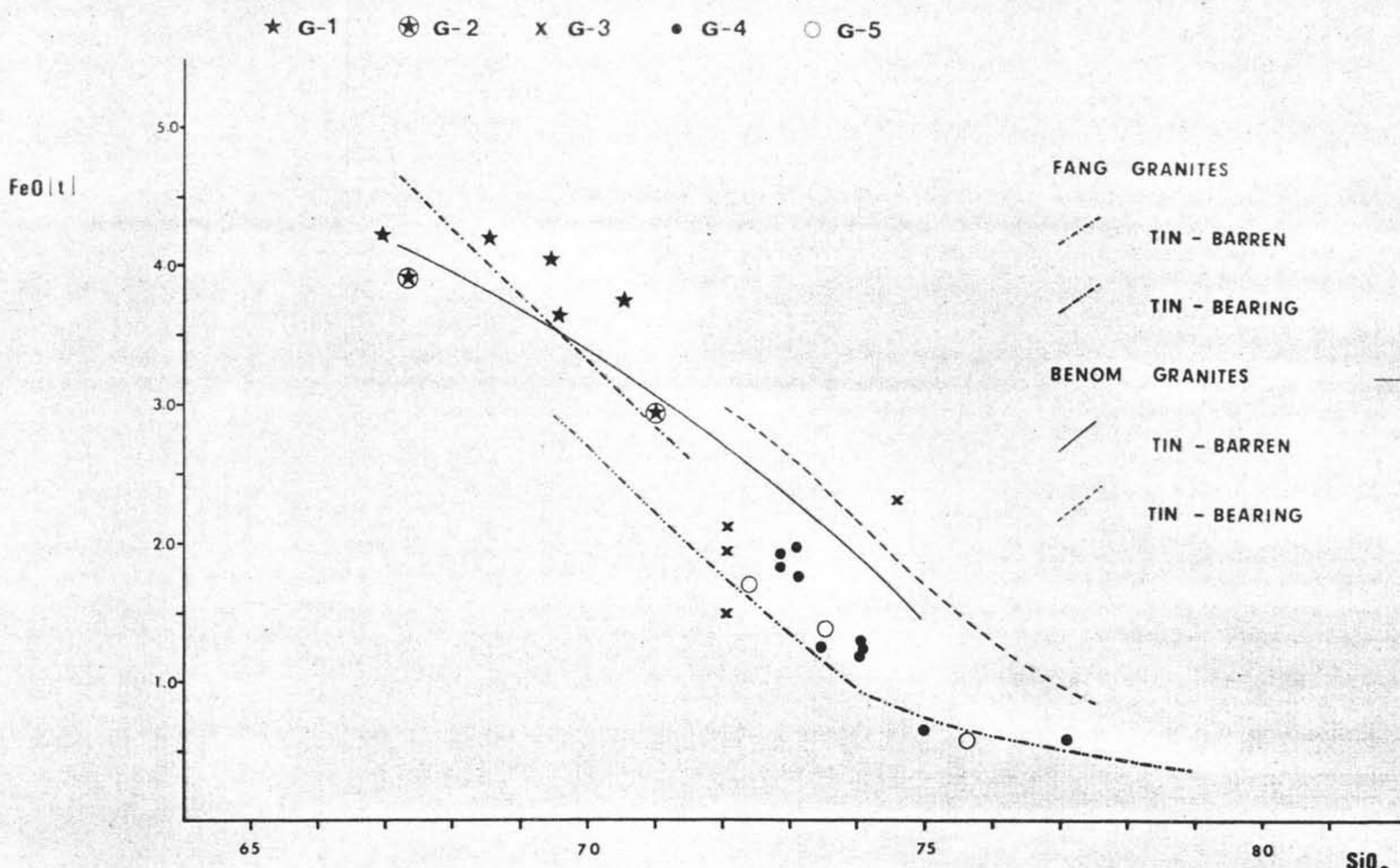


FIGURE 10. VARIATION OF FeO(t) AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

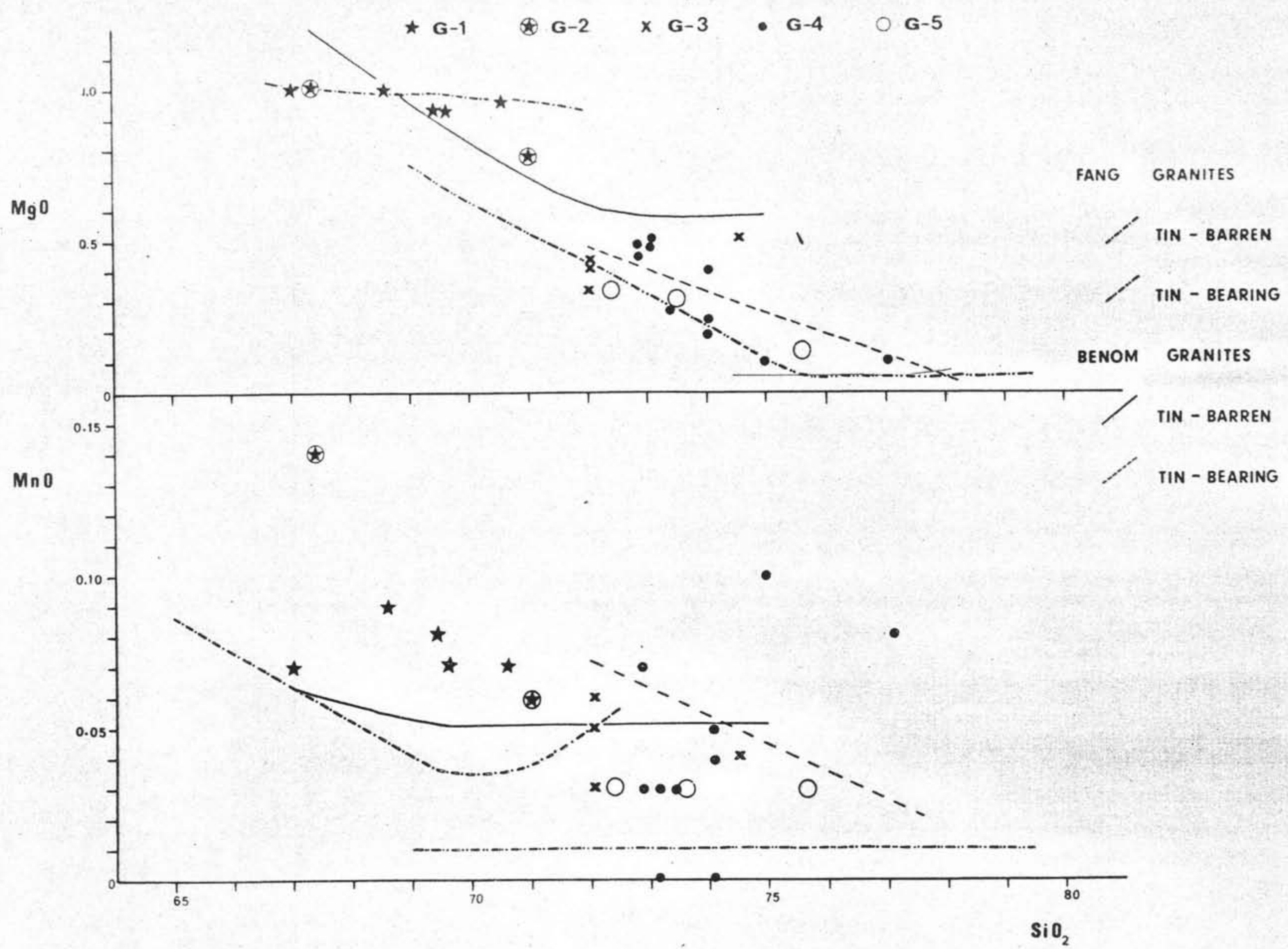


FIGURE 11. VARIATIONS OF MgO AND MnO AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

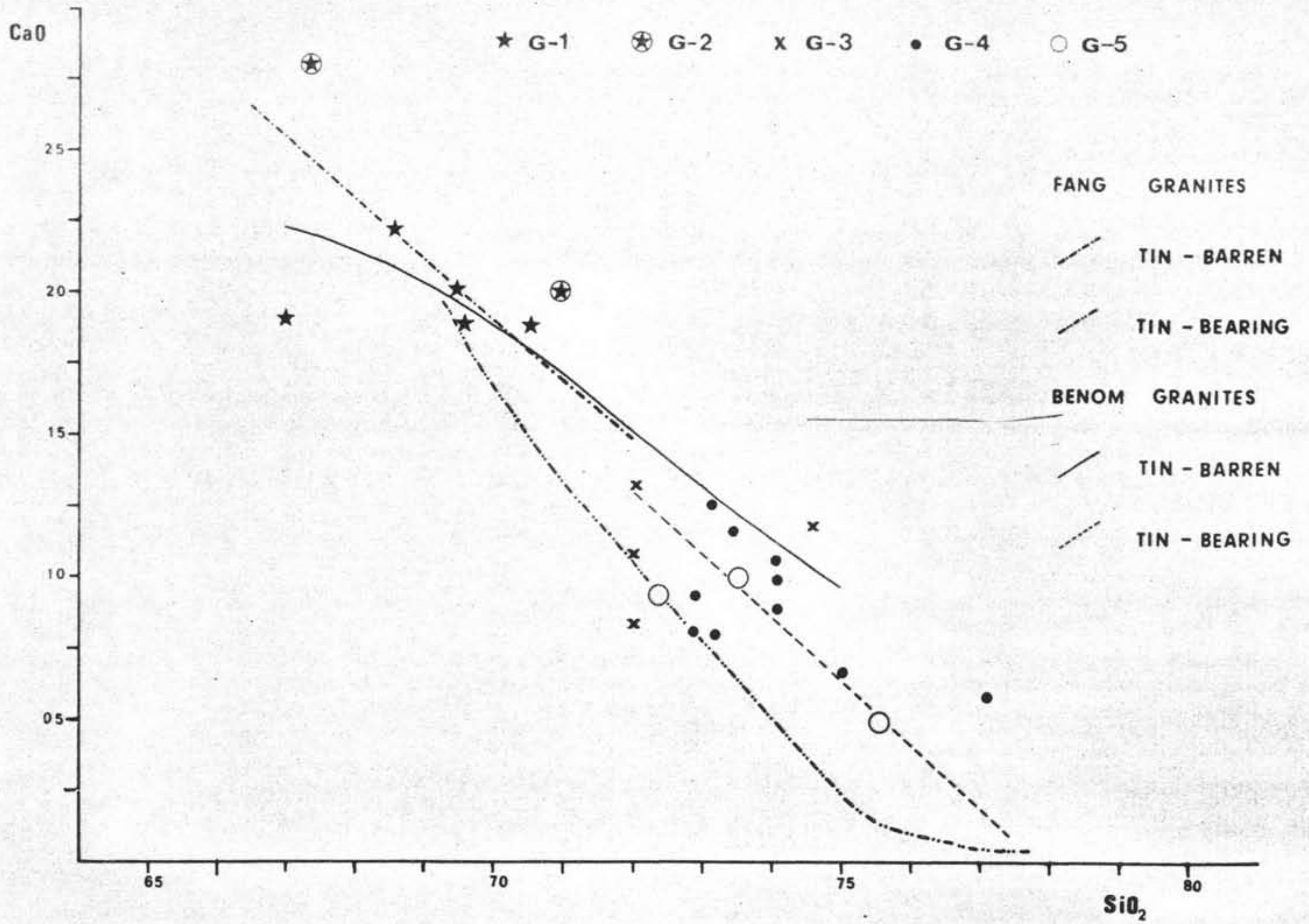


FIGURE 12. VARIATION OF CaO AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

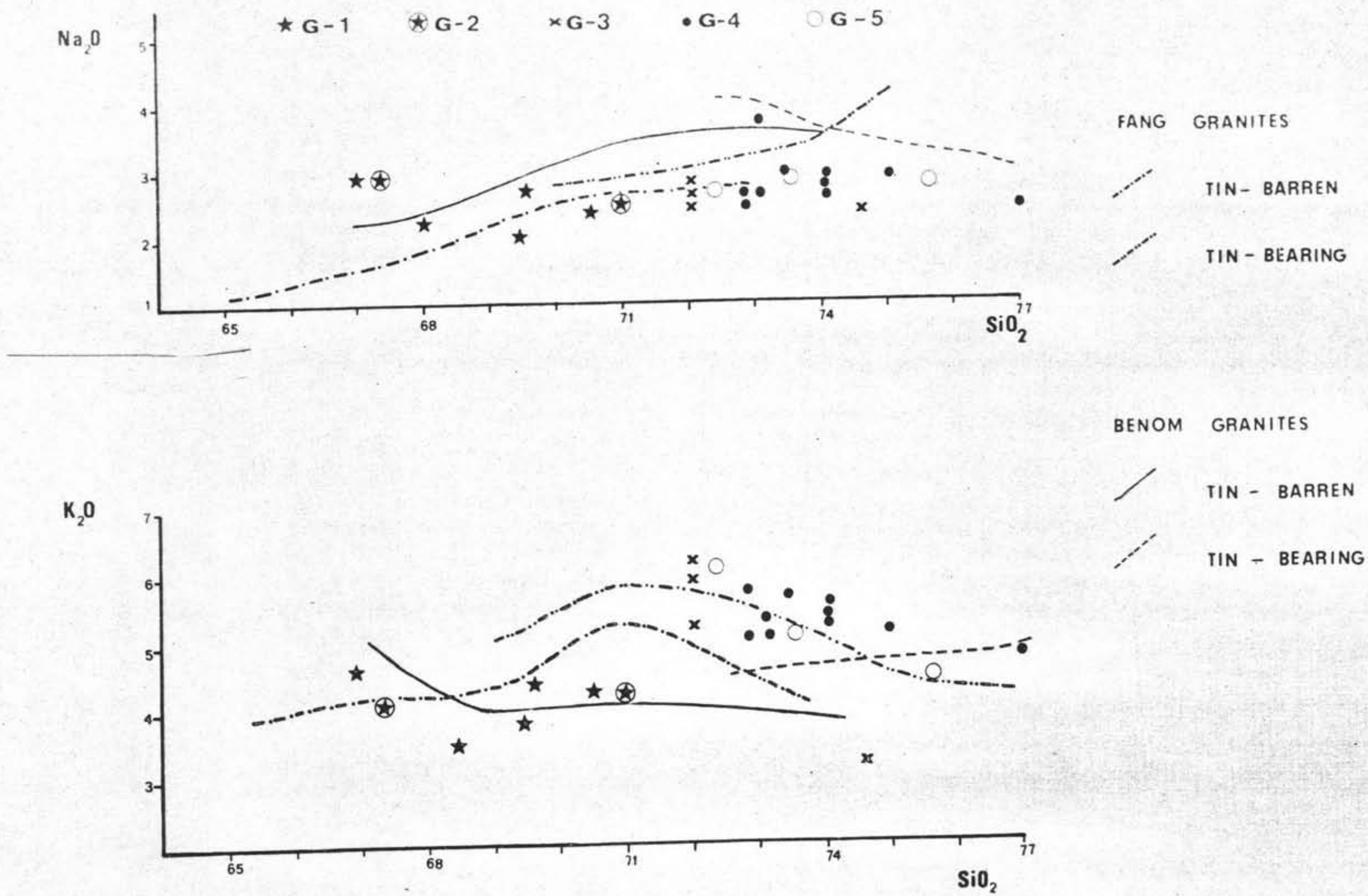


FIGURE 13. VARIATIONS OF Na_2O AND K_2O AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS

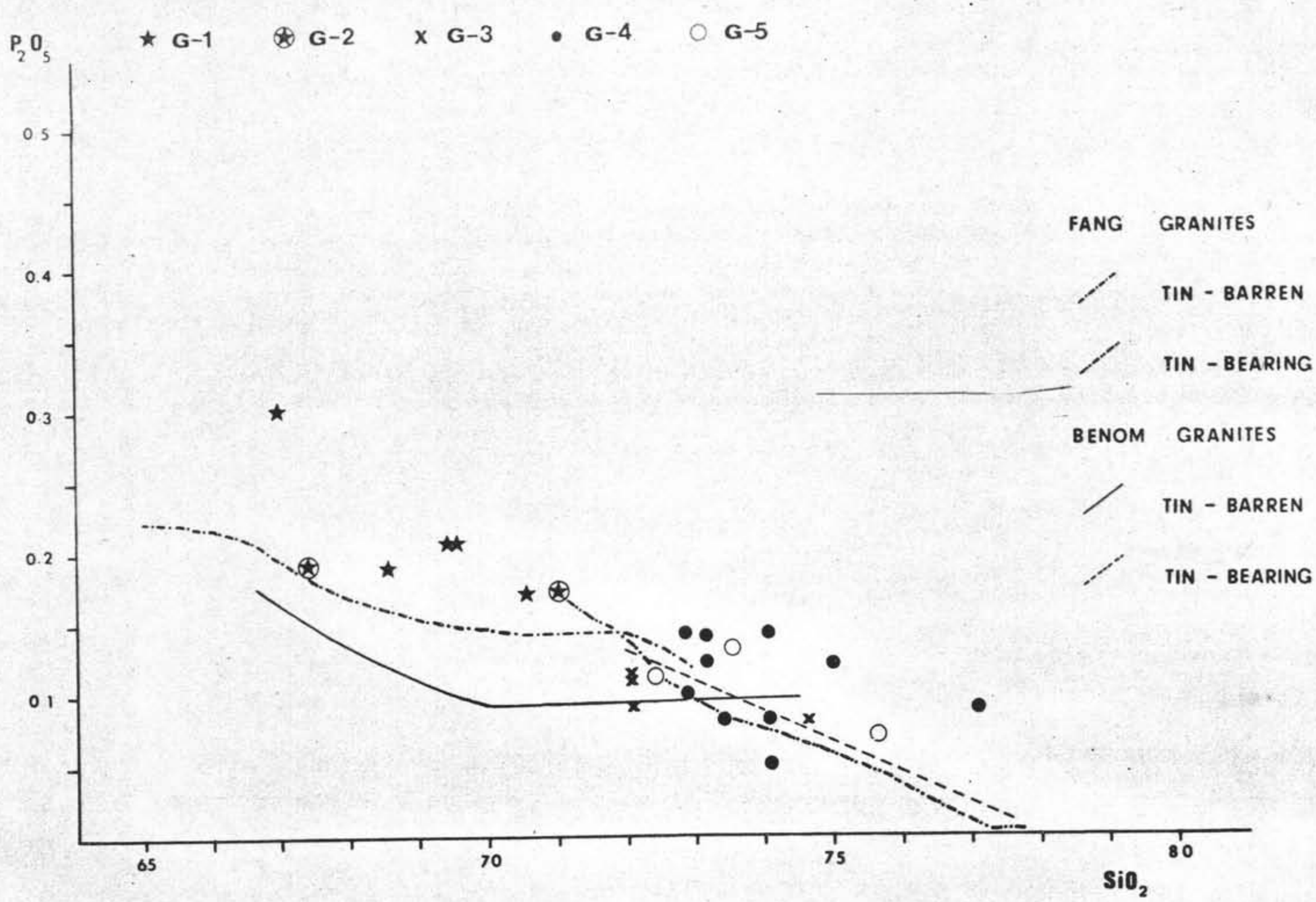


FIGURE 14. VARIATION OF P_2O_5 AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS.

7.2 Major-oxide and Trace-element Geochemistry

7.2.1 Major-oxide data

SiO_2 : The ranges of SiO_2 contents of each granite type are relatively restricted (66-77%), indicative of silicic composition (Table 2). The average percentage of SiO_2 is apparently lower in G-1 and G-2 and close to value of Fang tin-barren granites and lower than that of average granite (Taylor, 1968). The SiO_2 values of G-3, G-4, G-5 are relatively higher and nearly the contents of tin-bearing granites of many countries as expressed in Table 5. Consequently, G-1 and G-2 are principally less silicic type and G-3, G-4, and G-5 are relatively more silicic type.

TiO_2 : The TiO_2 contents of Phuket Plutons range from 0.05 to 0.69 percent. There are some differences in contents and distributions among the granite types (Figure 5). Average TiO_2 contents are higher in G-1 and G-2 and gradually decrease in G-3, G-4 and G-5, respectively (Table 4a). G-1 and G-2 have the average TiO_2 contents close to average granite (Taylor, 1968) and NE Queensland tin-barren granites (Sheraton & Labonne, 1978). G-3, G-4, G-5 have TiO_2 contents nearly the average tin-bearing granite (Stemprok & Skvor, 1974), biotite-muscovite granites of Khuntan Batholiths (Suensilpong, et al., 1977), and NE Queensland tin-bearing granites (Sheraton & Labonne, 1978). Figure 8 shows that the TiO_2 contents decrease as the SiO_2 contents increase. The trend of G-3, G-4 and G-5 is mostly conformed with that of Benom tin-bearing granites and of Fang tin-bearing granites whereas G-1 and G-2 trend is close to those of Benom and Fang tin-bearren granites.

Al_2O_3 : The Phuket-Plutons granites have rather high Al_2O_3 content with relative to the average granitic rocks compiled in Table 5. They have Al_2O_3 contents ranging from 13.15 to 16.55 percent. The Al_2O_3 contents in G-1 and G-2 are relatively high (mostly exceed 15.0%), whereas those of G-3, G-4 and G-5 are relatively low (mostly less than 15.0%). and slightly higher than the value of the average granite (Taylor, 1968). Variation diagram shows that the Al_2O_3 content decreases as the SiO_2 content increases (Figure 9). The G-1 and G-2 plots are close to the trend of Fang tin-barren granites, and the G-3, 4 and -5 plots are slightly near the trends of Benom and Fang tin-bearing granites.

FeO. (total): The total iron-oxide content of granites of Phuket Plutons varies widely from o.58 up to 4.2 percent. Most of total iron (as Fe_2O_3) against SiO_2 shows that total FeO is negatively correlated with SiO_2. In general, FeO trend is relatively high in G-1 and G-2 (close to the trend of Benom tin-barren granites) and sharply decrease in G-3, G-4, and G-5 which is systematically close to the trend of Fang tin-bearing granites (Figure 10). Figure 5 shows frequency distribution of total FeO content. It is worthy to note that G-1, G-2 have high total iron contents and close to average values of Tak Granites, average granite of Taylor (1968) and Almanden Granites. This can be distinguished from rather low values of G-3, G-4 and G-5 by this context. The average total iron oxide content of G-3, G-4 and G-5 are close to the average values of Elizabeth Creek Granites, Benom tin-bearing granites and Khun Tan Granites.

MnO : The MnO contents of G-3, G-4 and G-5, most commonly, fall within the ranges of 0.025 to 0.05 whereas those of G-1 and -2 vary from 0.05 to 0.15 (Figure 5). With the exception of 2 samples of G-4, MnO is generally negatively correlated with SiO_2 (Figure 11). The average percentage of MnO of G-1 and G-2 is rather high with relative to that of the average granite (Taylor, 1968). MnO of G-3, G-4 or G-5 is averagely close to those of biotite muscovite granites of Khuntan Granites and Indonisian and USSR tin-bearing granites (Table 5). When plotting against SiO_2, MnO trend of granites of Phuket Plutons cannot be correlated with any trends of Fang and Benom tin-bearing and-barren granites.

MgO : Frequency distribution and variation diagram in Figure 5 and 11, respectively show that MgO contents of most G-1 and G-2 ranges from 0.8 to 1.0 percent, and are higher than those of G-3, G-4 and G-5 (averaging 0.33 percent). MgO tends to decrease with increasing SiO_2 (Figure 11). Trend of G-1 and G-2 conforms with Fang tin-bearing granites whereas that of more silicic is quite consistent with those of Tak, Fang and Benom tin-bearing granites. Table 4a shows that G-1 and G-2 have a relatively restricted range of MgO content (averaging 0.95) which is slightly higher than value of Benom tin-barren granites. The more silicic type has lower MgO content nearly that of Benom tin-bearing granites but slightly lower than that of average tin-bearing granites of Stemprok and Skvor (1974).

CaO : The CaO content of Phuket Plutons ranges from 0.5 up to 2.79 percent. It is rather high in less silicic type with average value of 2.1 percent and close to that of average granite of Taylor (1968).

The more silicic type (G-3, G-4 and G-5) contains rather low CaO, having the average value of 0.9 percent and resemble those of NE Queensland tin-bearing granites and two mica granites of Khuntan Batholiths (Suensilpong et al., 1977). Such value appears to be slightly lower than that of average tin-bearing granites of Stemprok and Skvor (1974) and also close to that of average tin-bearing granites from USSR (Stemprok and Skvor, 1974). As depicted in Figure 12, CaO shows a tendency to decrease with increasing SiO_2. Trend of G-1 and G-2 is consistent with Fang tin-barren granites of whereas that of the more silicic type is quite similar to that of Benom tin-bearing granites.

$\underline{K_2O}$: The amount of K_2O of Phuket Plutons varies from 3.16 up to 6.19 percent (Figure 5). The silica variation diagram for K_2O shows a considerable scatter. As shown in Figure 13, G-1 and G-2 show little systematic variation with SiO_2 and slightly conform with the trend of Benom tin-bearren granites. The average value of the less silicic type is as the same as value given by Taylor (1968) of the average granite. K_2O of G-3, G-4 and G-5 is negatively correlated with SiO_2, and mostly close to trend of Fang tin-bearing granites. The average content of this more silicic group (5.2 percent) is rather high and relatively close to those of Fang tin-bearing granites and Cornwall tin-bearing ones (Stemprok and Skvor, 1974).

$\underline{Na_2O}$: The amount of Na_2O ranges restrictly from 2.0 to 3.66 percent. Figure 13 shows that most plots of the Na_2O contents show no correlation with the SiO_2, with the exception of some of more silicic type. The plots show a slight decrease as SiO_2 increases. However, as elucidated in Table 2(a), (b), (c) all the analyzed samples have lower

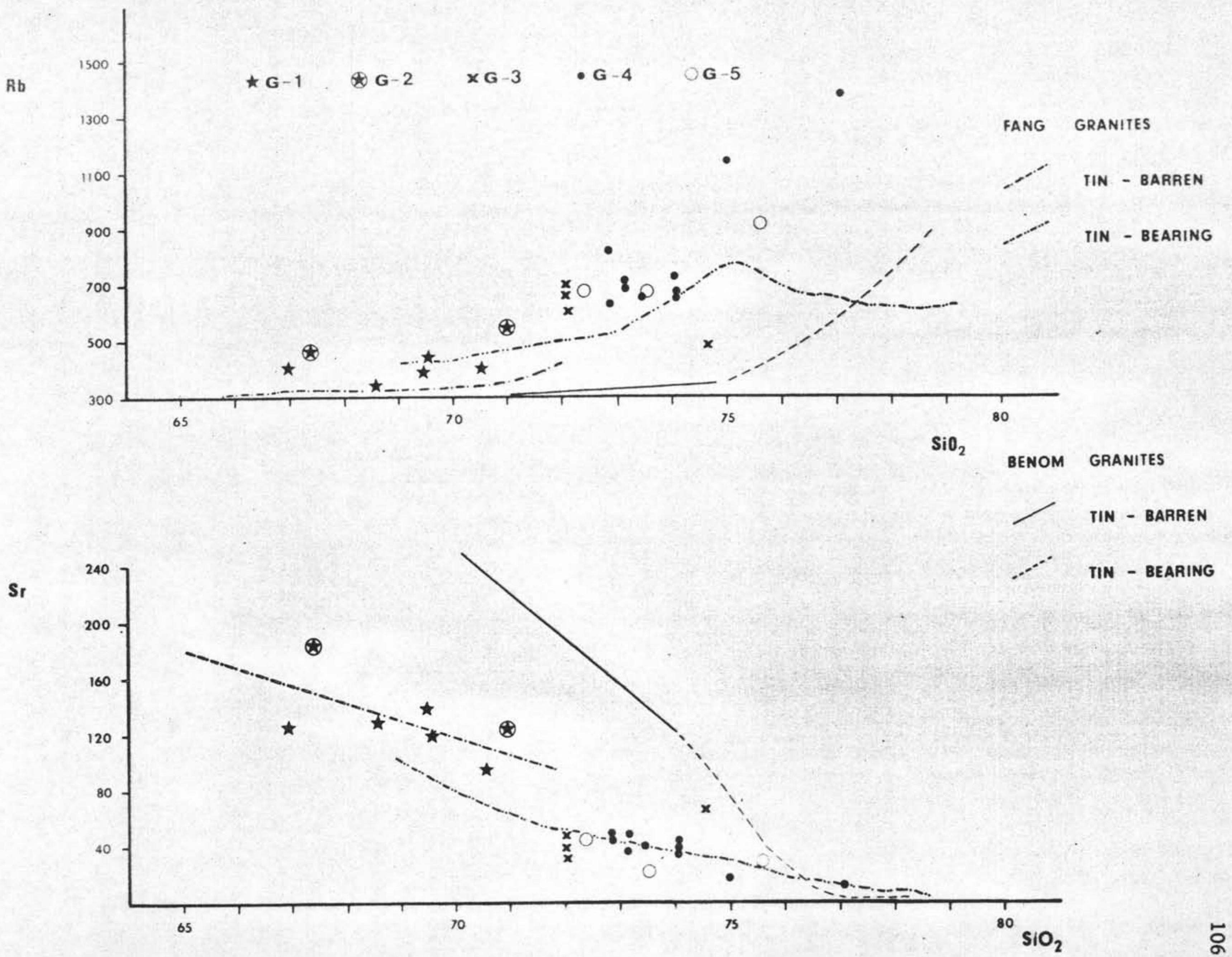


FIGURE 15. VARIATIONS OF Rb AND Sr AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS

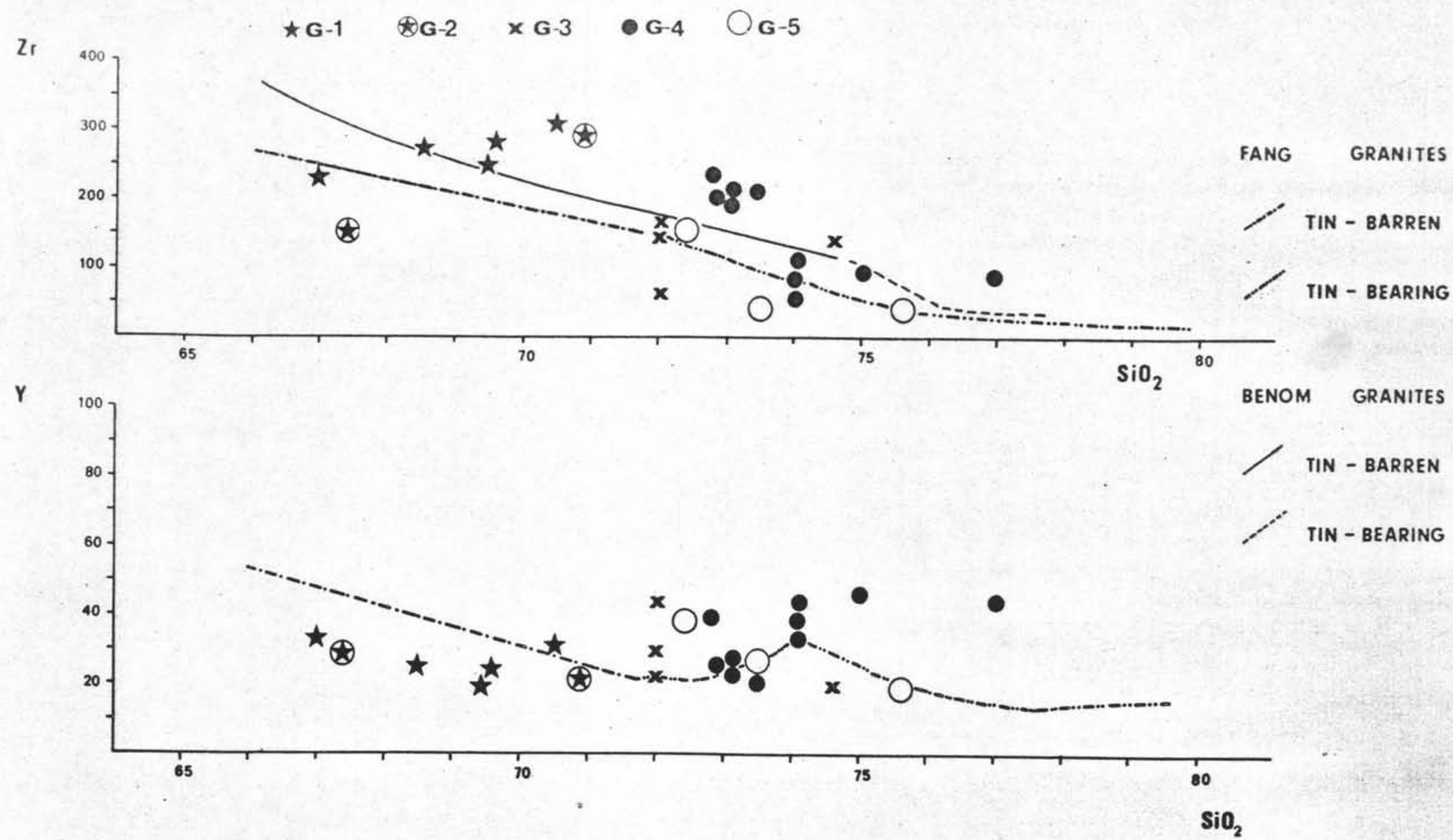


FIGURE 16. VARIATIONS OF Zr AND Y AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS

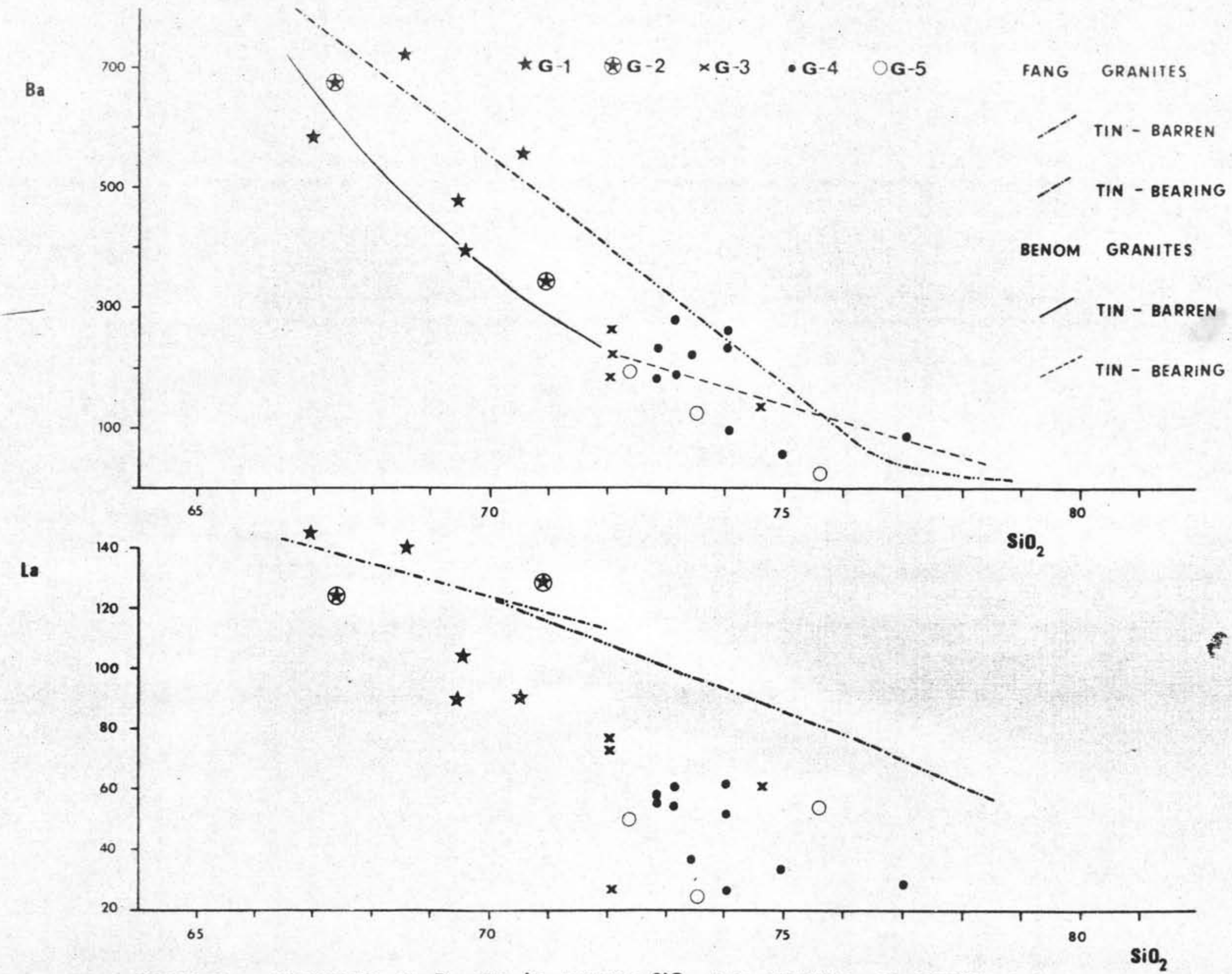


FIGURE 17. VARIATIONS OF Ba AND La AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS

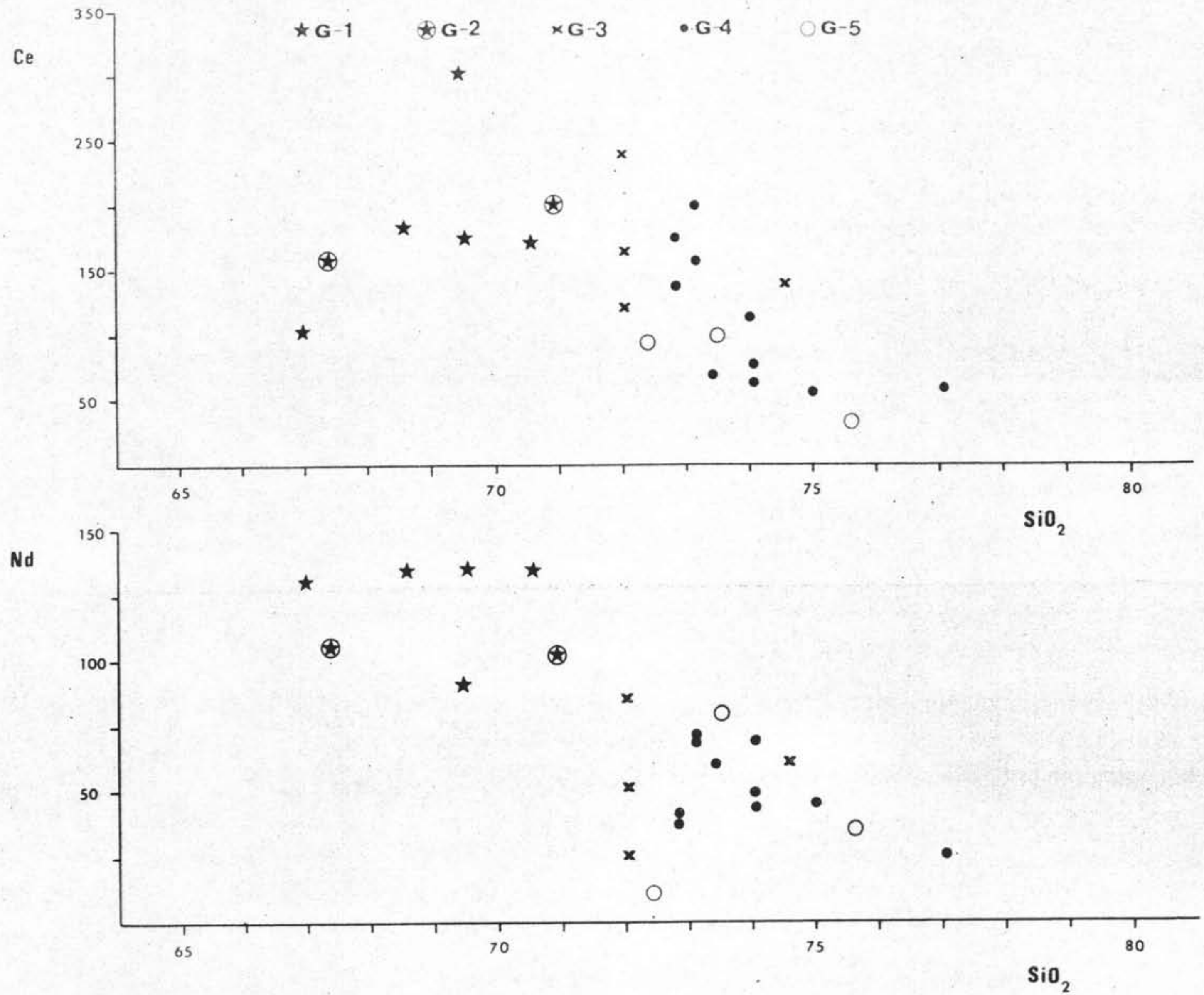


FIGURE 18. VARIATIONS OF Ce AND Nd AGAINST SiO_2 FOR GRANITES OF PHUKET PLUTONS

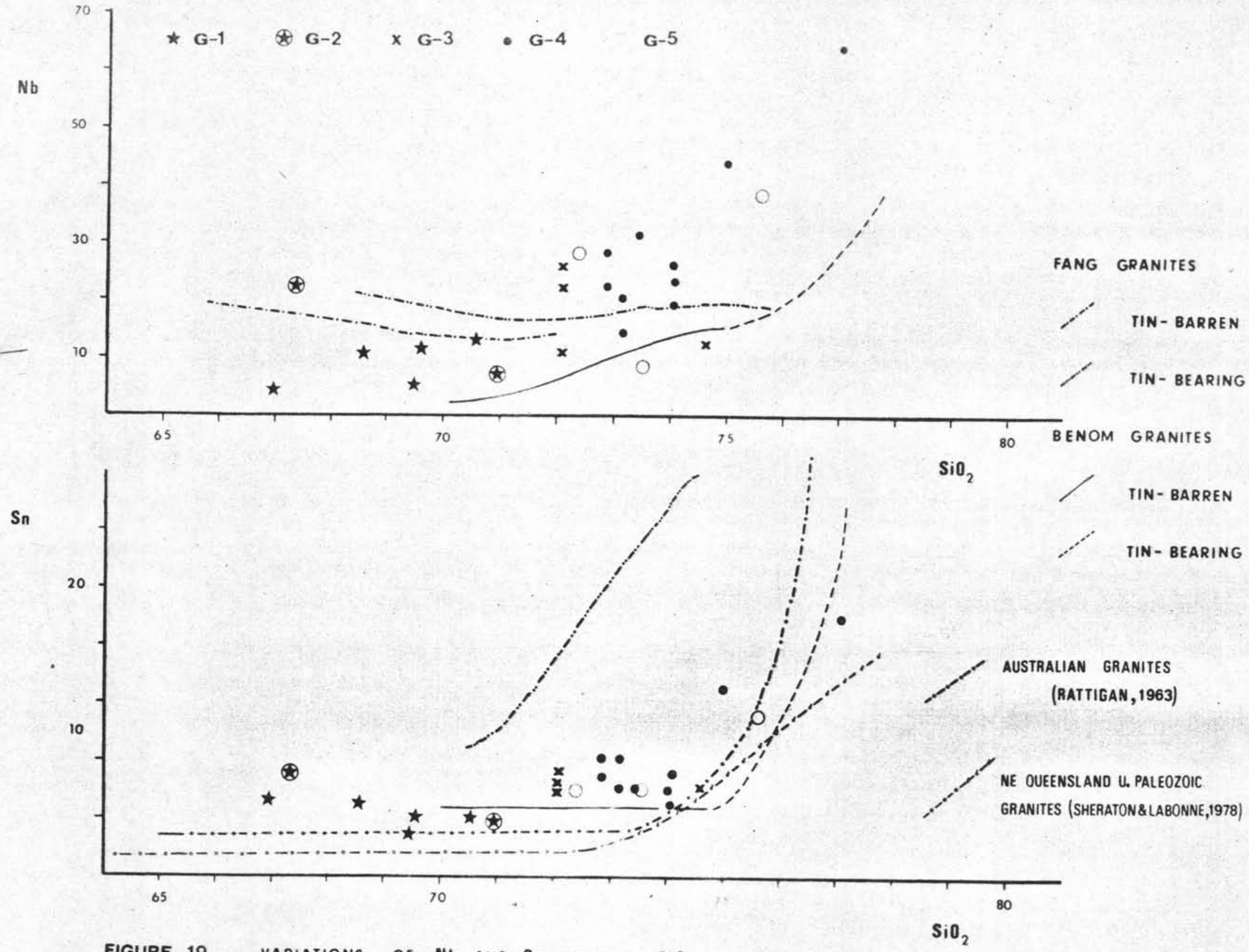


FIGURE 19. VARIATIONS OF Nb AND Sn AGAINST SiO_2 FOR GRANITS OF PHUKET PLUTONS.

Na_2O contents than the average granite of Taylor (1968). G-3, G-4 and G-5 has nearly similar in K_2O content to Indonesian tin-bearing granites (Stemprok and Skvor, 1974).

$\underline{P_2O_5}$: The P_2O_5 content tends to be better than that of the alkali contents when plotting versus SiO_2. Its trend clearly shows a negative decrease with increasing SiO_2 (Figure 14). The G-1, G-2 granites have higher P_2O_5 than average granite of Taylor (1968). The average P_2O_5 content of the more silicic type is much lower than that of average tin-bearing granites (Stemprok & Skvor, 1974) but is as the same as those of Indonesian and South Africa tin-bearing granites (Stemprok and Skvor, ob. cit.).

From these above data, most G-1 and G-2 have not only their compositions but also their trends nearly Fang and Benom tin-barren granites whereas those of G-3, G-4 and G-5 are more or less close to Fang and Benom tin-bearing granites.

7.2.2 Trace-element analyses

Rubidium (Rb) : Figure 15, 21 and 22 show that Rb concentrations distinctively increase with increasing SiO_2 and K_2O, but decrease with increasing Sr, respectively. Figure 6 illustrates that the less silicic type (i.e. G-1 and G-2) has the restrict Rb abundances with relative to the more silicic type (i.e. G-1, G-4 and G-5). Most of the G-1, G-2 granites have silimar Rb values and trend close to those of Fang tin-barren granites. The G-3, G-4 and G-5 granites have higher values of which their trend is conformed with those of Fang and Benom tin-bearing granites. The greisen granites contain considerably high values of Rb (approx. 2,000 ppm).

<u>Strontium</u> (Sr): Sr concentrations tend to have a positive correlation with CaO (Figure 21) and have a strongly negative correlation with SiO_2 (Figure 15) and Rb (Figure 22). All the samples analyzed are depleted in Sr with relative to value given by Taylor (1968) for his average granite. Strontium abundances seem to be higher in G-1 and G-2, intermediate amount in G-3, and rather lower in G-4 and G-5 (Table 4 b and Figure 6). A few of the greisen granites contain Sr as small value as 1 ppm. The G-1 and G-2 granites contain values of Sr nearly those of Fang, Benom, and NE Queensland tin-barren granites. The more felsic group (G-3, G-4 and G-5) contains Sr close to those of Fang, Benom, and NE Queensland tin-bearing granites. Sr trend of granites of Phuket Plutons is similar to those of Fang tin-bearing and - barren granites.

<u>Zirconium</u> (Zr): The Zr concentrations tend to decrease slightly with increasing SiO_2 (Figure 16). It is enriched in G-1, G-2 and relatively mildly depletely in G-4, G-3 and G-5 respectively (Table 4 b). However, greisen granites have to average Zr nearly G-2. Generally, G- 1 and G-2 has higher Zr abundances higher than average granite of Taylor (1968) and close to coarse-grained porphyritic granites of S. Africa (Kolbe & Taylor, 1966). The other types of granites, particularly G-3, G-4 as well as greisen granites have average concentration lower than values given by Taylor (1968) and close to the average values of Fang, Benom, and NE Queensland tin-bearing granite.

<u>Barium</u> (Ba) : Ba shows strong depletion as the silica content enriches in more amount. Table 4 b elucidates that it is distinctly higher in G-1 and G-2 and relatively lower in G-3, G-4 and G-5,

respectively. Greisen granites have averagely the lowest Ba content. As compared with the average value given by Taylor (1968) in Table 6, all the analyzed granites have lower in Ba concentration. The average Ba contents of G-3, G-4 and G-5 are close to that of Elizabeth Creek Granites. It is important to note also that the Ba values of granites in the area studied are plotted in the same trend of Fang and Benom tin-bearing and-barren granites (Figure 17).

Yttrium (Y) : The heavy rare-earth like element, Y, in the silica variation diagram (Figure 16) shows that concentration increase slightly with increasing SiO_2. Average Y abundances in G-1 and G-2 (26 ppm) are nearly the average values reported for Fang tin-barren granites. The concentrations are slightly higher in G-3, G-5 and G-4, respectively (Table 4 b). The average Y of G-4 is close to values of Taylor (1968) for his average granites (Table 6) and is slightly lower than those of Fang and NE Queensland tin-bearing granite. The average greisen granite has the highest Y concentration, ranging from 47 to 110 ppm. The Y trend of Phuket Plutons is exactly opposite to that of the Fang Granites.

Niobium (Nb) : When plotting the Nb concentration versus SiO_2, the variation diagram shows a rather smooth positive correlation (Figure 19). As illustrated in Table 4b and Figure 6, the Nb content seems to be relatively low in G-1 and G-2 and slightly increasing in more felsic type (G-3, G-5 and G-4, respectively). The greisen granites have the average Nb content 2 times greater than G-4 (Table 4b). The Nb concentrations of G-1 and G-2 are quite similar to those reported by Garson, et al (1975) for their coarse-grained biotite granites from Phuket and Phangnga Region, whereas those of G-3, G-4 and G-5 are higher than those of biotite-muscovite granite of the same region. The Phuket-Plutons granites have the Nb trend mostly conformed with that of the Benom Granites.

Lanthanum (La) : The silica variation diagram (Figure 17) shows that La has a strong tendency to decrease with increasing SiO_2. It is rather high in G-1 and G-2 (average 117.5 ppm), intermediate in G-3 and low in G-4, G-5 as well as greisen granites, respectively (Table 4b). Most of the rocks analyzed cannot be correlated with the average granites (Table 6). The exceptions are those values of G-4 and G-5 having nearly the La contents as those of average granite of Taylor (1968). When plotting La against SiO_2, the La trend is conformed with the trend of Fang tin-bearing and - barren granites. High amount of light rare earth element (La, Ce, and probably Nd) reflect the accessory mineral contents, particularly sphene and allanite (Llyakovich, 1967, Sheraton and Labonne, 1978) as well as apatite (Fairbridge, 1972; Bateman & Chappel, 1979). These accessories are quite abundance in G-1, G-2 and rarely found in the more silicic group.

Cerium (Ce) : The other type of light rare earth metal, Ce, show systematically lower in concentration when SiO_2 increases (Figure 18). Table 4b also shows that G-1 and G-2 have higher Ce concentration and 2 times above that of the average granite of Taylor (1968). G-3, G-4, and G-5 have a decrease in Ce and most values are also close to that of NE Queensland tin-bearing granites. The Ce trend is approximately the same as that of La (i.e. negatively correlated with SiO_2).

Neodymium (Nd) : Nd, the light rare earth metal, tends to show a strongly negative correlation with SiO_2 (Figure 18). The G-1 and G-2 granites contain high amount of Nd (average 100 ppm) whereas the G-3, G-4 and G-5 granites contain relatively low Nd amount (average 45 ppm) (Table 4b). The greisen granites have averagely the lowest Nd abundances with relative to the other types of granites.

Tin (Sn) : Sn tends to show a strongly positive correlation with SiO_2 (Figure 19). It increases significantly with high differentiation and where the SiO_2 exceeds 75 percent the Sn contents increase in considerable amount (more than 10 ppm). As expressed in Table 4b, it was found that Sn ranges from 3 to 7 ppm in G-1 and G-2, mostly 6-7 ppm in G-3, widely ranging from 5 to 19 ppm in G-4 and is restrictly limited in 6 ppm in G-5. The highest amount of Sn is found in greisen granite with the average value of 75.25 ppm (Table 4b). It was found also that all the specimen analyzed have average Sn contents much higher than value given by Taylor (1968) for his average granites. It is worthy to note that trace amounts of Sn contents in G-3, G-4, G-5 and greisen granite are significantly higher than the high Sn-values of some granites shown in Table 6. When comparing with the Sn trends of Australian granitic rocks (Rattigan, 1964) and 206 granites of NE Queensland (Upper Paleozoic ages) (Sheraton & Labonne, 1978), the trend of Phuket Plutons (Figure 19) is higher.

To summarize, silica variation diagrams show normal calc-alkali trends for most elements-TiO_2, Al_2O_3, FeO (T), MnO, MgO, CaO, P_2O_5, Sr, Ba, La, Ce, Nd and probably Zr decrease, and K_2O, Rb, Nb, Sn, and possibly volatile & H_2O components (as L.O.I) increase with differentiation. Na_2O and Y show little systematic variation although both tend to increase with increasing SiO_2.

The biotite-muscovite granites (i.e. G-4, G-5 and possibly G-3,) have higher SiO_2 and possibly K_2O, Rb, Nb, Sn, and Y and lower TiO_2, Al_2O_3, FeO (t), MnO, CaO, P_2O_5, Sr, Ba, La, Ce, Nd and possibly Zr than the biotite granite (G-1, G-2). The C I P W norms as shown in Table 2a, 2b, 2c reveal that the averages of albite, anorthite hypersthene, apatite, ilmenite, and magnetite norms for G-1 and G-2 are relatively higher than those of G-3, G-4 and G-5. Besides these, the average differentiation incices (D.I.) of G-1 and G-2 are much lower than those of G-3, G-4 and G-5. The plots of all major oxides versus D.I. are given in Figure 25a, 25b and 25c.

7.3 Differentiation Trends of Phuket Plutons

When the alkalinity ratio of Wright (1969) is plotted against the SiO_2 contents, the majority of samples of Phuket Plutons show a typically calc-alkaline affinity becoming more alkaline with increasing SiO_2 content (Figure 20), although some of the more silicic rocks are either close to or fall within the alkaline field. This appears to be characteristic of many generally calc-alkaline associations (Ewers and Scott, 1977; Sheraton & Labonne, 1978).

Some elemental ratios commonly used as indicators of increasing fractionation in granitic rocks are increasing Fe/Mg ratios (Kolbe, 1966)

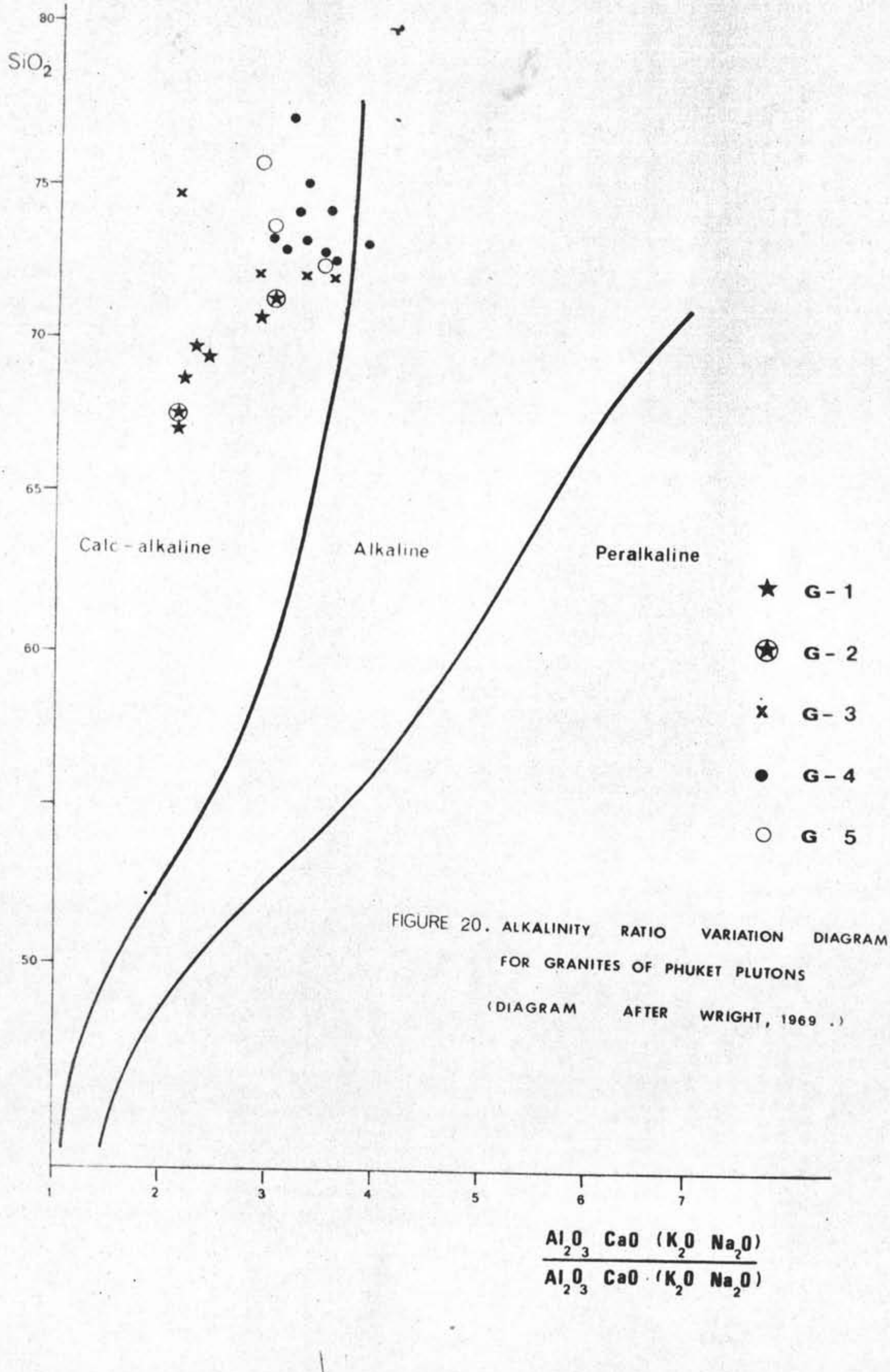


FIGURE 20. ALKALINITY RATIO VARIATION DIAGRAM FOR GRANITES OF PHUKET PLUTONS (DIAGRAM AFTER WRIGHT, 1969 .)

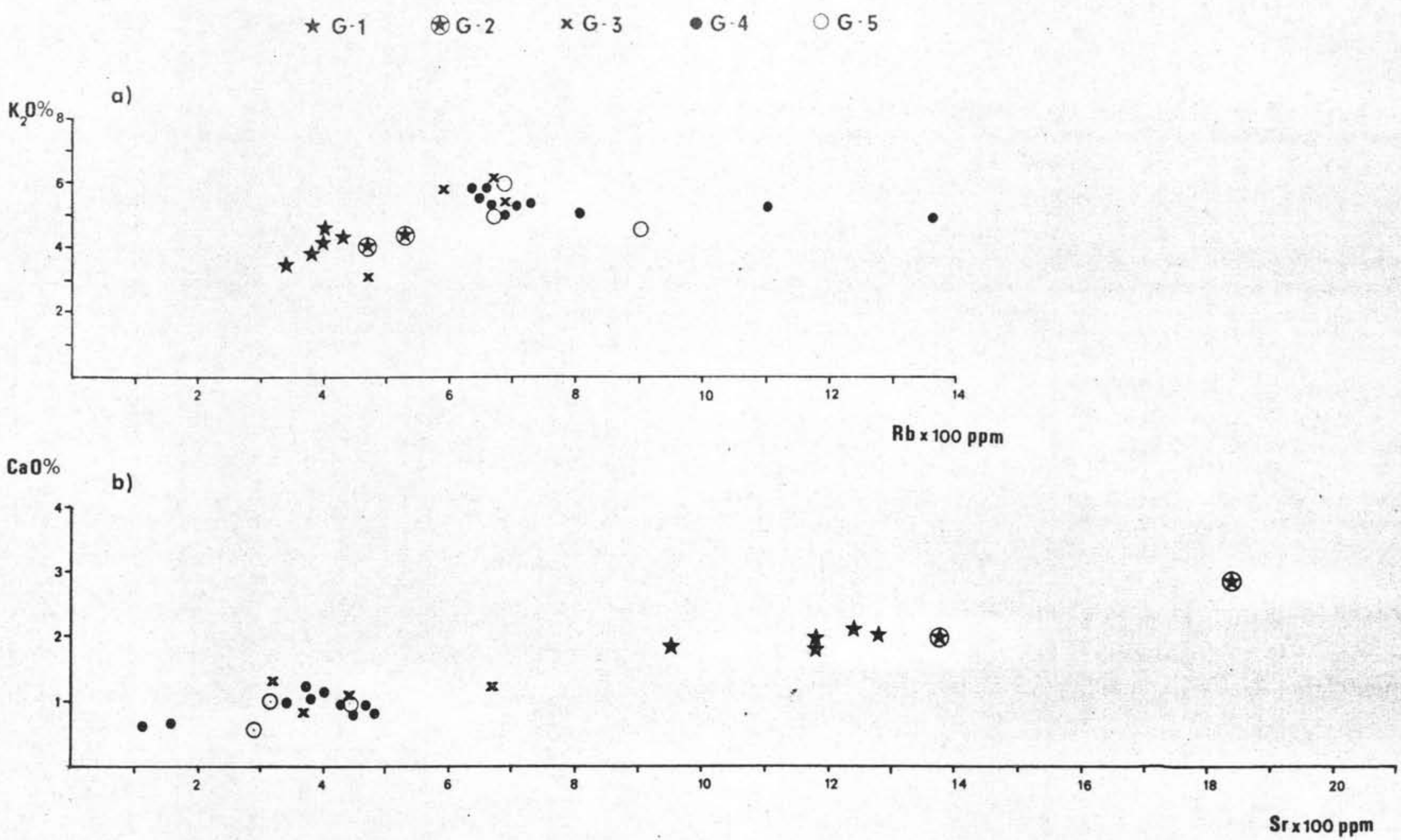


FIGURE 21. VARIATIONS OF K_2O VERSUS Rb (a) AND CaO VERSUS Sr (b) FOR GRANITES OF PHUKET PLUTONS

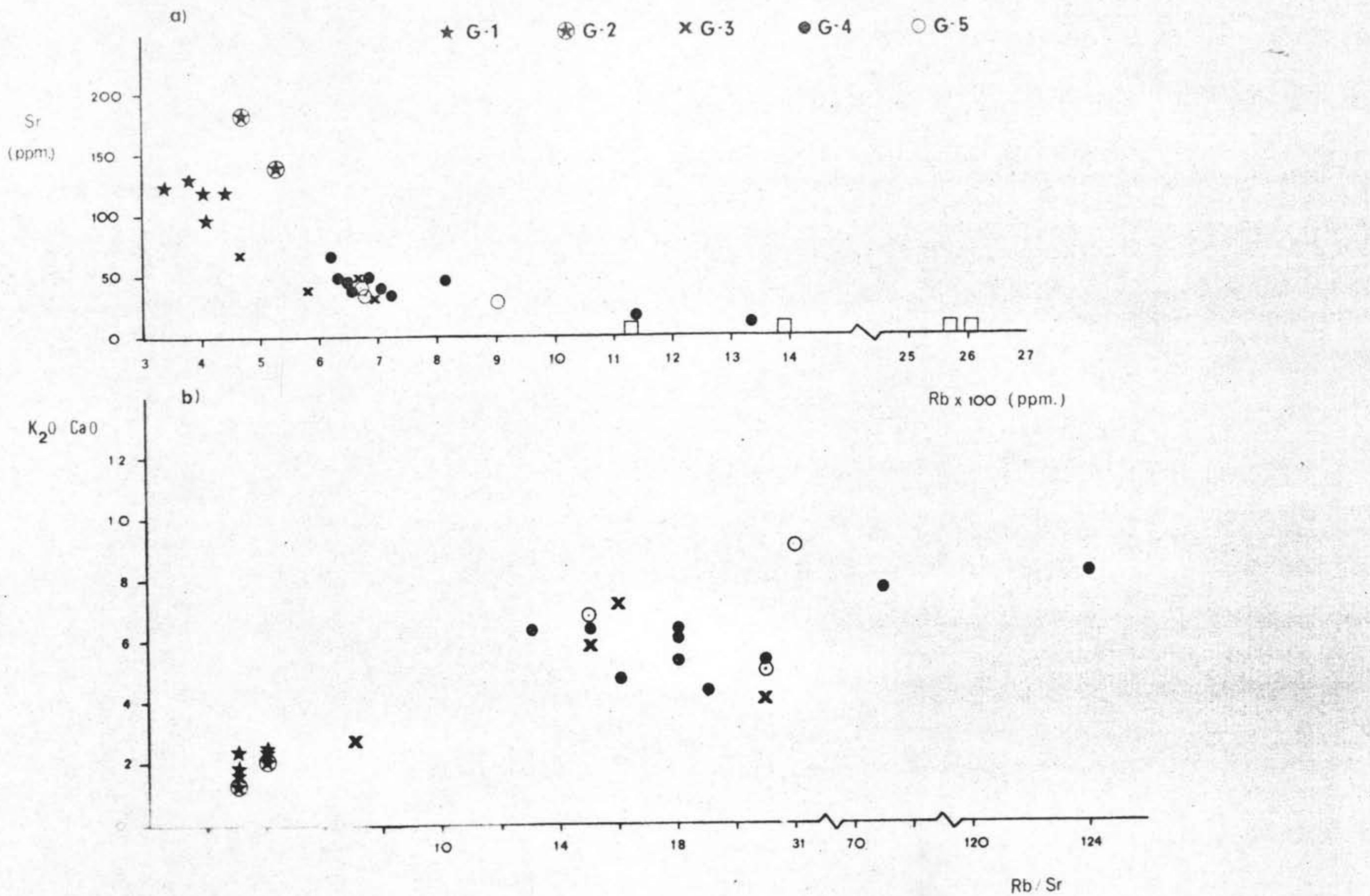


FIGURE 22. VARIATIONS OF Sr VERSUS Rb (a) AND K_2O/CaO VERSUS Rb/Sr (b) FOR GRANITES OF PHUKET PLUTONS

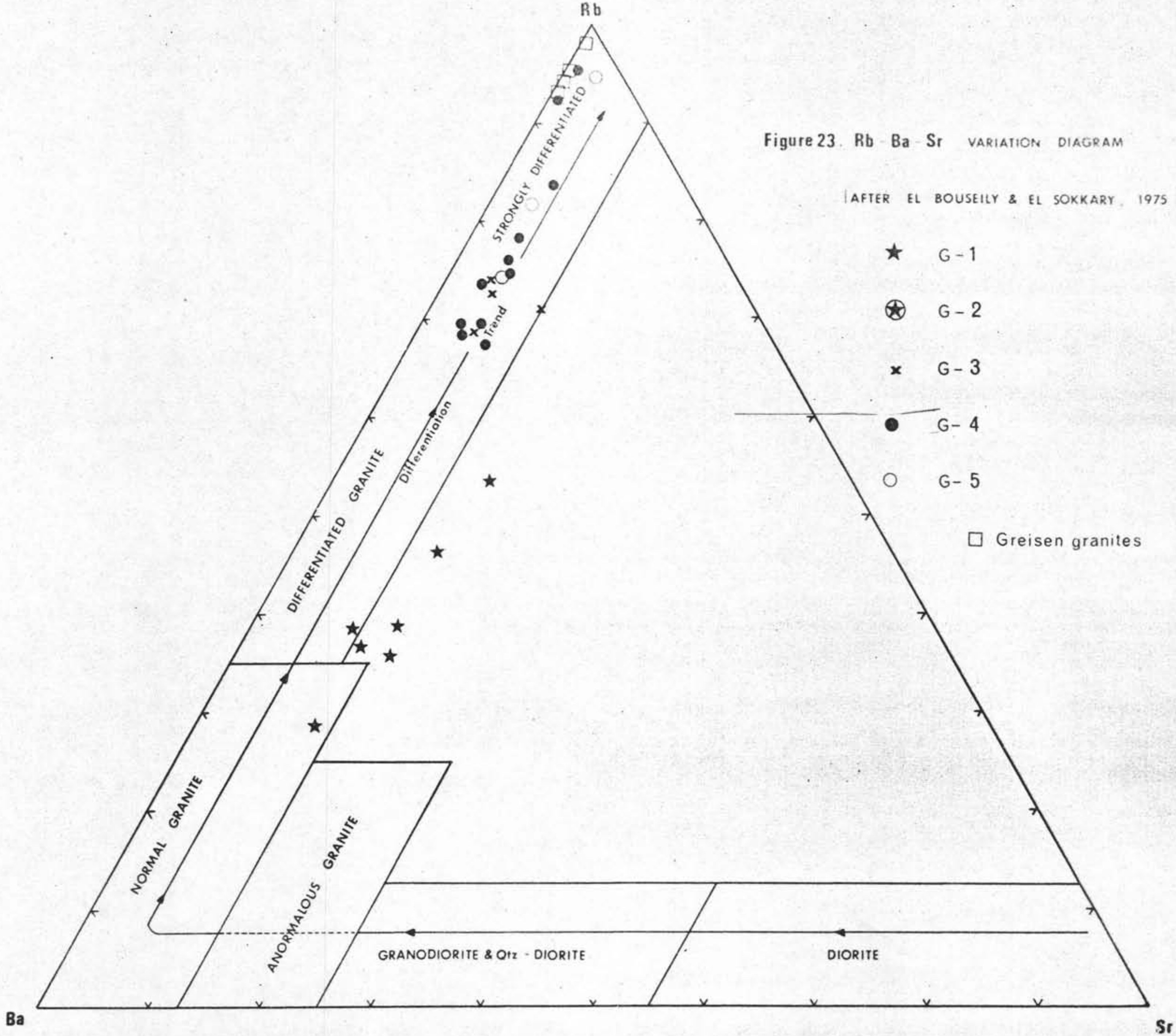


Figure 23. Rb - Ba - Sr VARIATION DIAGRAM

(AFTER EL BOUSEILY & EL SOKKARY, 1975).

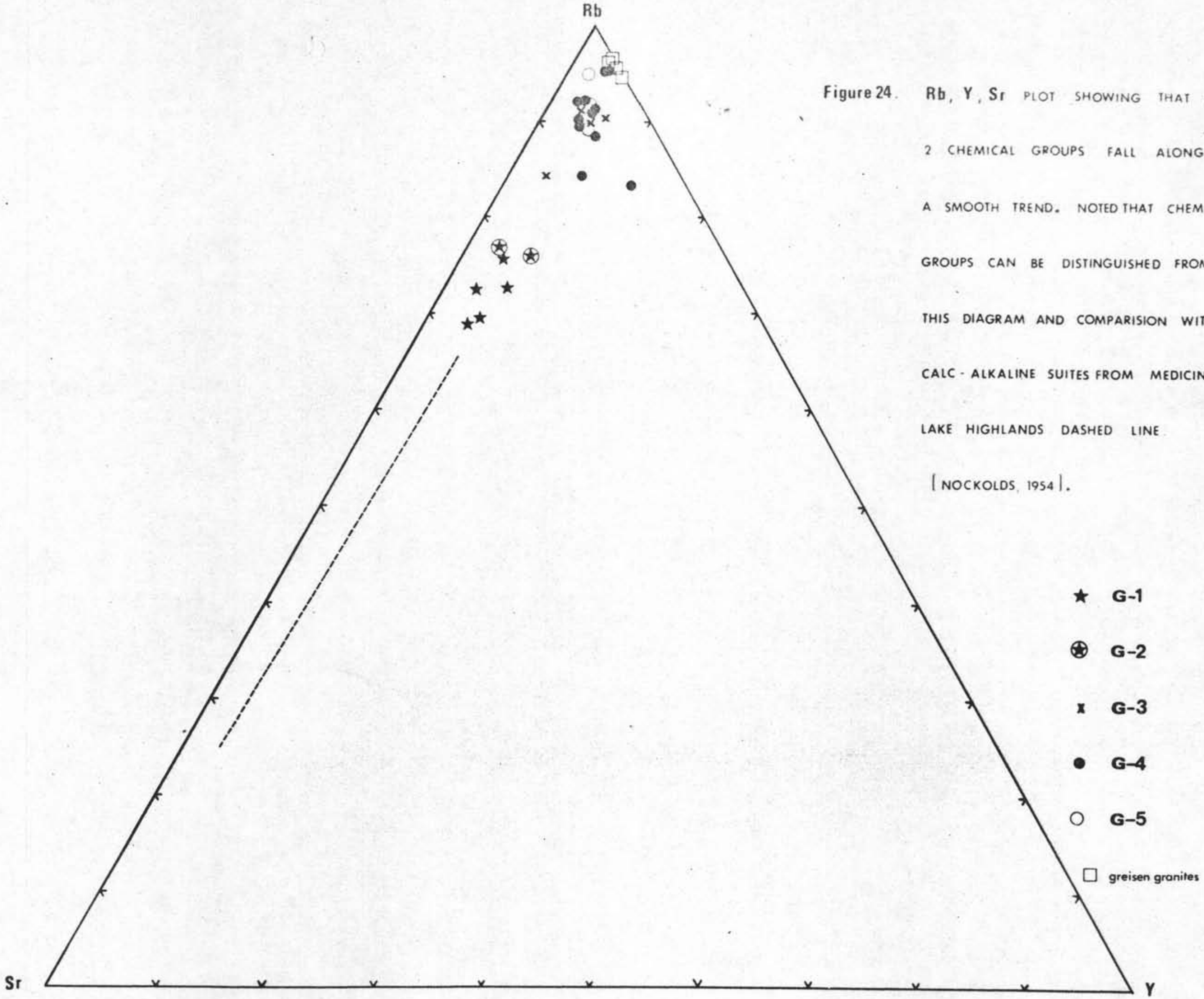


Figure 24. Rb, Y, Sr PLOT SHOWING THAT THE 2 CHEMICAL GROUPS FALL ALONG A SMOOTH TREND. NOTED THAT CHEMICAL GROUPS CAN BE DISTINGUISHED FROM THIS DIAGRAM AND COMPARISION WITH CALC - ALKALINE SUITES FROM MEDICINE LAKE HIGHLANDS DASHED LINE [NOCKOLDS, 1954].

and decreasing Mg/Li ratios (Kuts and Mishchenko, 1963). Though, the Li contents of the analyzed granites of Phuket Plutons have not been determined, the Fe/Mg ratios of G-1 and G-2 range mostly from 4 to 5 as compared with ratios of 6 up to 8 for G-3, G-4 and G-5. Binary elemental variation diagram (Figure 21, 22, 31) indicate that the G-4, G-5 and possibly G-3 is relatively more depleted in Sr, Ba, and Ca and enriched in Rb and K than G-1 and G-2. Such enrichment and depletion are well known features in crystallization products of late-stage residual melts (Taylor, et al., 1968, Ewers and Scott, 1977). Many authors, i.e. Taylor, et al. (1956), Taylor, et al. (1968), Groves (1972), Sheraton and Labonne (1978) have observed a similar enrichment in Rb relative to K and depletion in Ca, Sr, and Ba in Cornwall granites, Snowy Mountains leucogranites, Blue Tier two-mica granites, and NE Queensland Upper Paleozoic granites, respectively. They have suggested that these rocks crystallized from a melt which had already undergone considerable differentiation. The useful data present in Figure 7 show frequency distribution of elemental ratios of Phuket Plutons. The more silicic types (i.e. G-3, G-4, G-5 and also greisen granites) have higher Rb/Sr, K/Ba, Ba/Sr, and Ca/Sr as well as lower K/Rb, Ba/Rb, and Ca/Y than the lower silicic type (G-1 and G-2). As illustrated also in Figure 22, G-1 and G-2 have rather low K_2O/CaO and Rb/Sr whereas G-3, G-4, G-5, on the contrary, have relatively high K_2O/CaO and Rb/Sr suggesting that the G-3, G-4 and G-5 granites show the more intensive differentiation. Such cases seem to be semilar to NE Queensland Upper Paleozoic granites which Elizabeth Creek Granites are the late stage product (Sharaton & Labonne, 1978).

It has been previously accepted that because the ionic and atomic properties of Rb are similar to K, and Sr to Ca. These interrelated elements should be strongly positive correlated (Heir and Billings, 1970, Groves and Taylor, 1978). Rb is commonly enriched in residual liquids resulting from fractionation as well as Sr is depleted in late crystallization due to the element capture in early formed minerals (Fairbridge, 1972). The ratic K/Rb less than 160 generally occur in strongly differentiated granites and pegmatites while Ca/Sr ratios generally increase (Taylor, 1965; Bradshaw, 1967, Groves, 1972). The K/Rb ratios of the biotite granites are relatively low (average 82 ppm) and Ca/Sr ratio averages 125 ppm suggesting that they are somewhat fractionated. The K/Rb ratios of the biotite-muscovite granites (average 60 ppm) are exceptionally low and average Ca/Sr ratio is about 200 ppm being considered to be an indicative of extreme fractionation.

In addition to these, the Phuket Plutons data have been plotted in the Rb-Ba-Sr ternary diagram with the field determined by El Bouseily & El Sokkary (1975) and the direction of differentiation is also superimposed (Figure 23). Although, many of the G-1 and G-2 data do not fall exactly within the nominated fields, the interpretation is open without protestion that all the granites are highly fractionated, and biotite-muscovite granites (G-3, G-4 and G-5) show more differentiation, the greisen types exhibit extreme differentiation as well. The other triangular variation diagram of trace element proportions (i.e. Rb, Sr, Y) seems also significant and was firstly used by Smith (1972) in order to distinguish among the acid igneous rocks having slightly varied or non-varied major oxide concentration and to define whether the rocks have undergone more or less differentiation. The present data are plotted accompanied with the trend of calc-alkaline suite from Medicine Lakes Highlands (Nockolds, 1954), showing that all the analyzed rocks show highly differentiated particularly those of G-3, G-4 and G-5 (Figure 24). And the greisen granites are extreme differentiated as compared with the normal calc-alkaline line.

From the previous mentioned data, it should be summarized that the granites of Phuket Plutons are of calc-alkaline suite with somewhat fractional differentiation and that the biotite-muscovite affinities (i.e. G-3, G-4, G-5) exhibit more differentiation than the biotite ones (i.e. G-1 and G-2). The greisen granites seem to show extreme differentiation with relative to all other types.