CHAPTER 4

GEOCHEMISTRY

As a supplement to the petrographic studies, forty-two rock samples were collected for whole-rock chemical analyses. Eleven samples are rhyolitic tuff, four samples are rhyolite, seven samples are dacite, eitht samples are andesite, six samples are diorite, three samples are granodiorite, and three samples are granite. Location of these samples are shown in Figures 4 a, 4 b, 4 c and 4 d.

All of the analytical works were carried out by the analytical section, geological survey division, Department of Mineral Resources. The standard chemical data and CIPW norms of forty-two rock samples are presented in Table 4.1. Table 4.2 gives the chemical analyses of trace elements whereas Table 4.3 illustrates the chemical parameters.

In order to evaluate the results of the chemical data, several diagrams were prepared to show chemical variation among different kinds of rocks. These diagrams include QAP diagram, SiO_2 variation diagrams, SI variation diagrams, MgO variation diagrams, AFM diagram, alkali-silica diagram, alkalinity ratio variation diagram, and trace element variation diagrams.

4.1 Major Element Variations

For most of the volcanic rocks in the study area, modal mineral contents cannot be accurately determined because of the

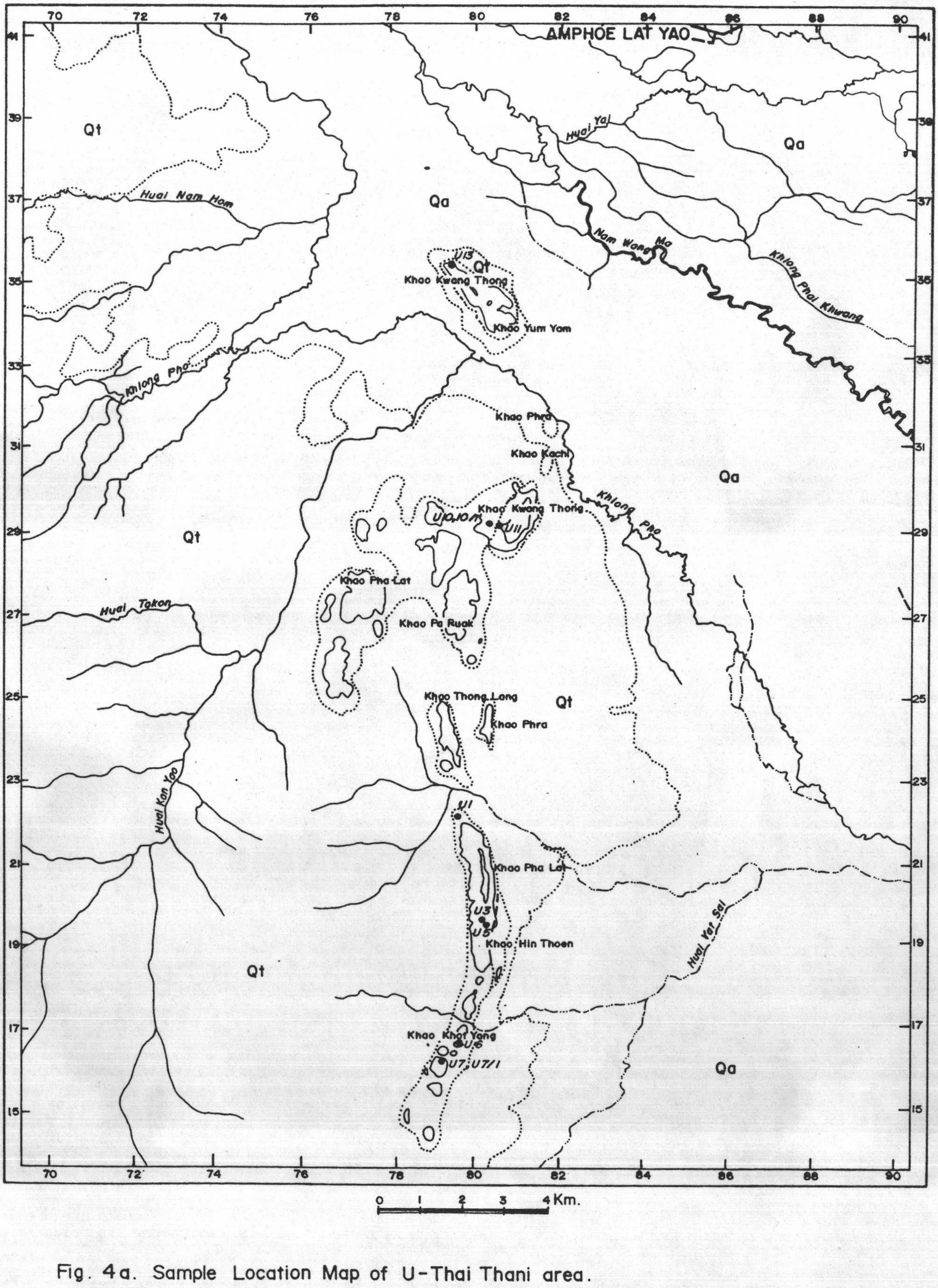


Fig. 4a. Sample Location Map of U-Thai Thani area.

● Location of Sample.

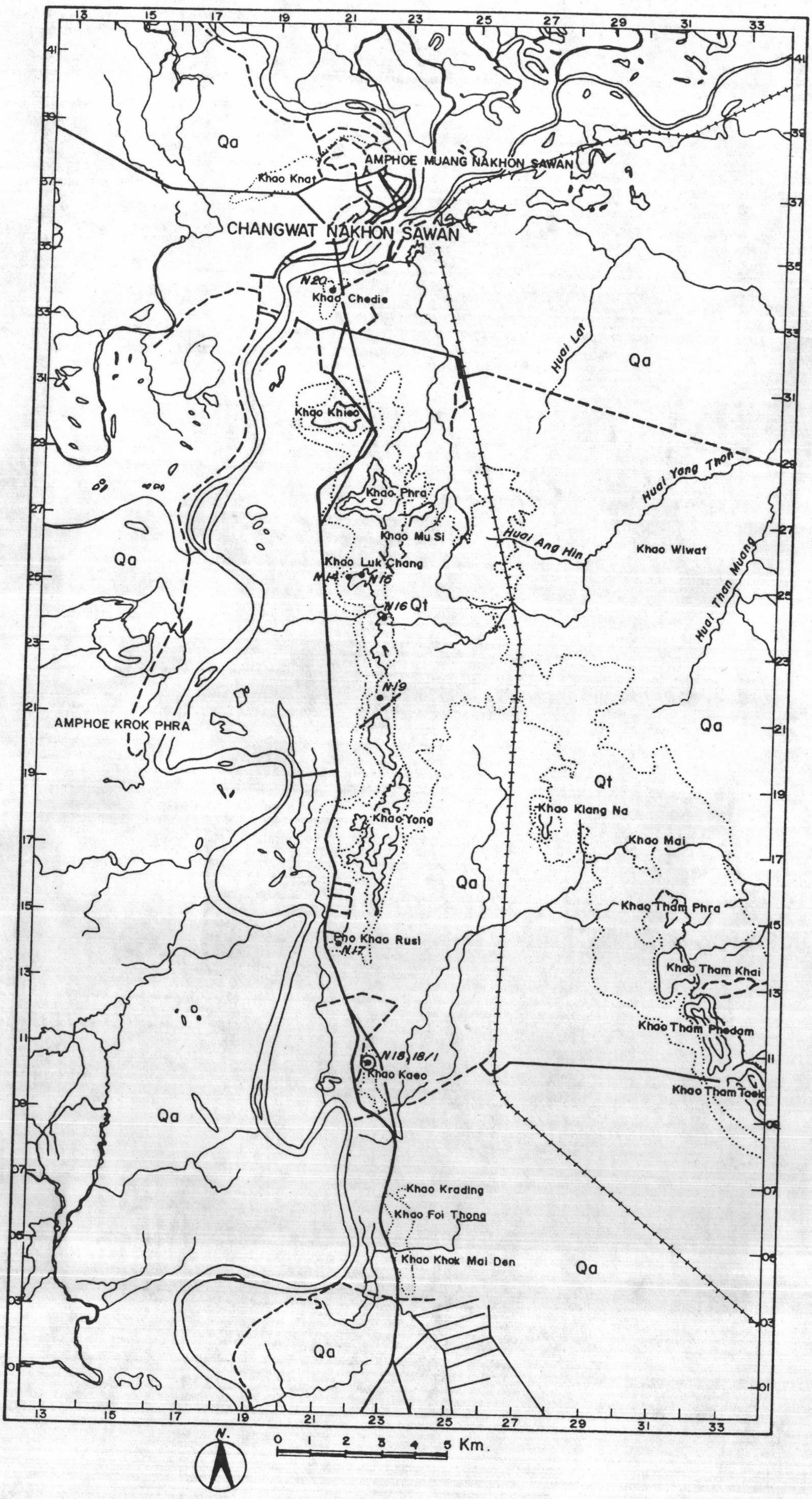


Fig. 4 b Sample Location Map of Nakhon Sawan.

● Location of Sample.

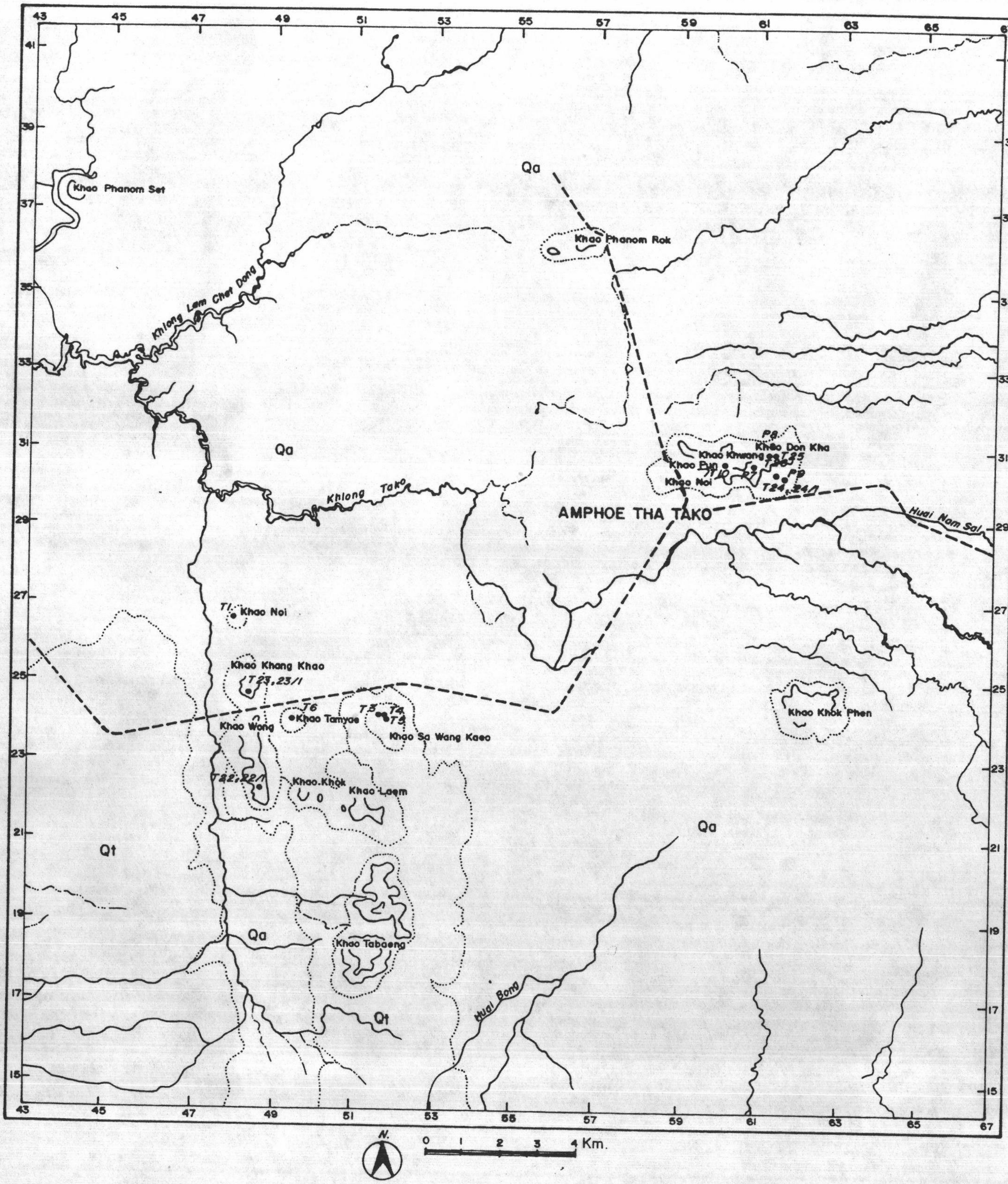


Fig. 4c Sample Location of Tha Tako area.

● Location of Sample.

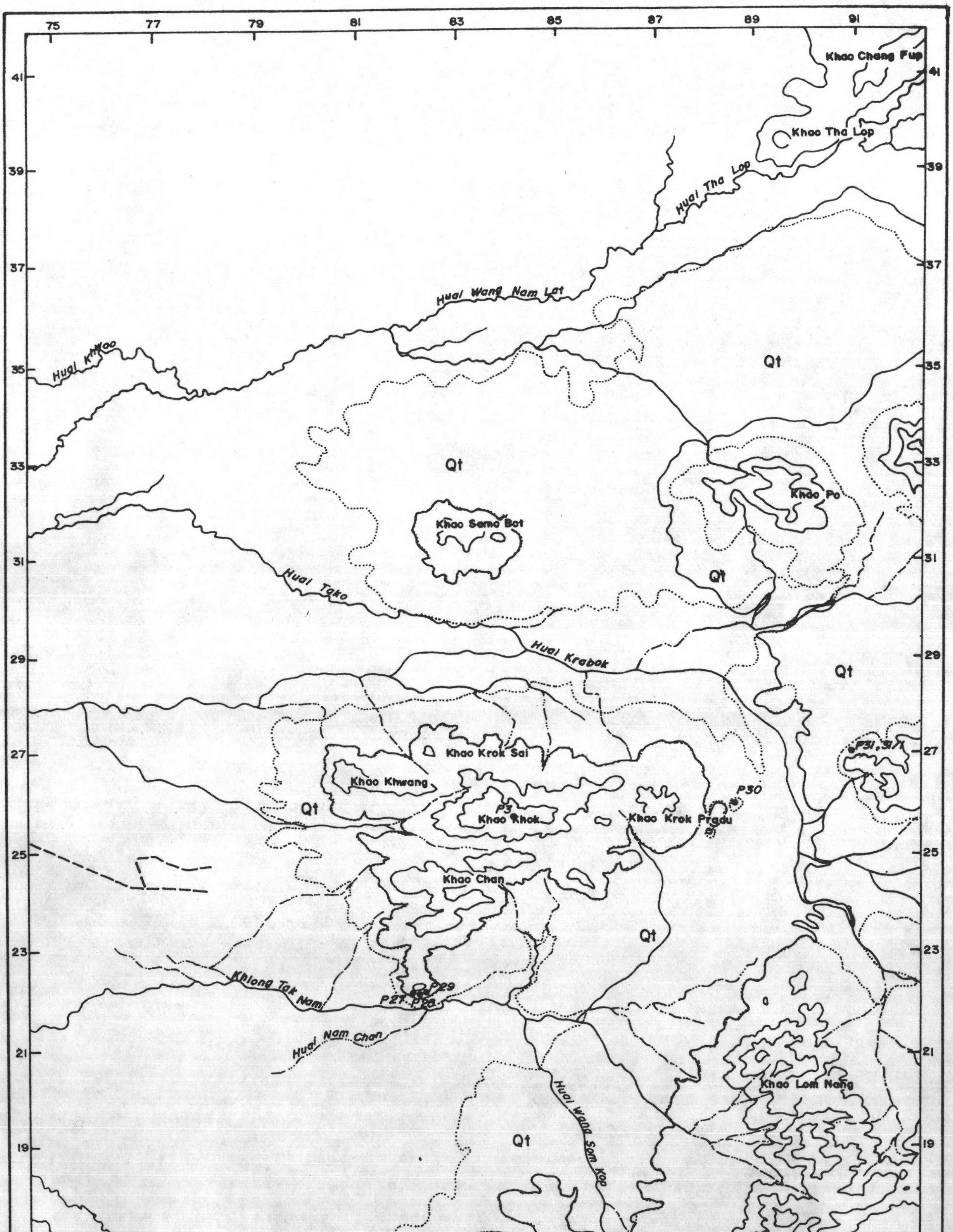


Fig. 4d Sample Location of Phai Sali area.

● Location of Sample.

Table 4.1 Major element-oxide analyses and CIPW norms.

Rock Type		Andesite						
Sample No.	U 6	N 14	N 16	N 18	T 24/1	T 26	P 8	P 31/1
Major element oxdies (wt%)								
SiO_2	57.30	53.77	54.10	54.82	58.10	59.57	55.64	51.60
TiO_2	0.95	2.10	1.40	0.46	0.84	0.60	0.96	1.60
Al_2O_3	18.16	15.50	15.10	15.90	15.70	14.59	14.70	14.00
Fe_2O_3	1.93	6.66	5.13	4.68	3.18	1.54	4.51	7.90
FeO	4.90	4.52	5.71	4.69	6.22	6.45	5.71	2.61
MnO	0.10	0.16	0.17	0.16	0.30	0.27	0.28	0.18
MgO	2.80	4.40	4.30	5.51	2.80	2.33	3.36	4.52
CaO	7.00	7.18	6.40	9.20	6.69	4.63	7.96	9.40
Na_2O	3.40	3.10	4.85	0.90	3.95	1.02	3.37	4.28
K_2O	0.82	0.09	0.28	0.07	0.72	7.51	0.67	0.48
P_2O_5	0.20	0.60	0.18	0.06	0.18	0.12	0.15	0.23
S	0.01	0.00	0.02	0.00	0.15	0.35	0.38	0.01
H_2O^-	0.21	0.26	0.08	0.10	0.14	0.16	0.25	0.27
H_2O^+	2.22	1.09	2.27	3.45	0.55	0.84	0.41	2.04
CIPW norms								
Q	13.379	15.917	5.870	20.928	12.831	9.552	12.107	4.589
C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
or	4.845	0.532	1.654	0.414	4.254	44.374	3.959	2.836
ab	28.770	26.231	41.039	7.616	33.424	8.631	28.516	36.216
an	31.868	28.112	18.604	39.138	22.982	13.055	23.005	17.571
di	1.279	2.796	9.631	4.890	7.497	7.679	12.738	21.454
hy-fs	5.708	0.000	2.903	3.727	5.707	6.976	3.953	0.000
hy-en	6.635	9.662	7.384	11.941	5.198	4.324	4.900	1.311
ol	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
mt	2.798	9.003	7.438	6.786	4.611	2.233	6.539	4.326
hm	0.000	0.450	0.000	0.000	0.000	0.000	0.000	4.916
il	1.804	3.988	2.659	0.874	1.595	1.140	1.823	3.039
ap	0.463	1.389	0.417	0.139	0.417	0.278	0.347	0.533
py	0.019	0.000	0.037	0.000	0.218	0.655	0.711	0.019
Total	97.568	98.082	97.637	96.452	98.796	98.895	98.598	97.777

Rock Type	Dacite							Dacite - Rhyolite	Rhyolite		
Simple No.	T 1	T 3	T 5	T 10	T 25	P 7	P 9	T 22	T 22/1	T 23	T 23/1
Major element oxide (wt%)											
SiO_2	73.220	71.50	72.05	68.00	66.28	63.14	74.09	70.30	65.90	75.00	65.20
TiO_2	0.41	0.31	0.33	0.50	0.42	0.79	0.33	0.38	0.46	0.39	0.43
Al_2O_3	12.96	14.87	14.10	14.52	16.70	14.26	12.76	13.20	15.90	13.00	15.10
Fe_2O_3	1.43	1.93	1.68	1.59	0.90	4.76	1.94	2.15	1.84	1.80	0.74
FeO	0.70	1.12	1.29	4.54	3.27	3.19	2.20	0.76	2.04	0.27	2.67
MnO	0.05	0.09	0.15	0.19	0.12	0.19	0.11	0.07	0.08	0.05	0.11
MgO	0.39	0.69	0.76	0.93	0.85	2.17	0.67	0.50	1.13	0.13	1.15
CaO	1.99	1.04	1.03	2.00	3.01	5.40	2.15	2.12	1.22	0.13	3.21
Na_2O	4.53	5.26	5.38	4.89	4.15	3.30	3.66	4.10	5.01	3.45	5.35
K_2O	2.82	2.65	2.53	1.02	2.85	0.82	1.54	4.15	4.16	4.40	3.20
P_2O_5	0.08	0.13	0.11	0.14	0.10	0.19	0.08	0.11	0.18	0.28	0.16
S	0.00	0.00	0.00	0.08	0.05	0.00	0.04	0.01	0.00	0.00	0.05
H_2O^-	0.31	0.23	0.20	0.25	0.13	0.19	0.17	0.25	0.24	0.21	0.21
H_2o^+	1.12	0.39	0.83	0.87	0.21	1.29	0.60	1.40	1.11	0.55	1.81
CIPW norms											
Q	32.032	27.820	27.720	27.468	21.665	26.930	40.611	26.553	16.314	37.900	13.560
C	0.000	1.769	0.902	2.070	1.555	0.000	1.355	0.000	1.368	2.560	0.000
or	16.662	15.658	14.949	6.027	16.840	4.845	9.099	24.521	24.580	26.000	18.908
ab	38.332	44.509	45.524	41.378	35.116	27.924	30.970	34.639	42.393	29.190	45.270
an	6.701	4.311	4.392	9.008	14.280	21.675	10.144	5.359	4.878	0.000	7.737
di	2.062	0.000	0.000	0.000	0.000	3.069	0.000	2.686	0.000	0.000	5.961
hy-fs	0.000	0.118	0.715	6.386	4.688	0.753	2.014	0.000	1.615	0.000	2.008
hy-en	0.015	1.718	1.893	2.316	2.117	4.175	1.669	0.000	2.814	0.320	1.561
Ol	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
mt	1.231	2.798	2.436	2.305	1.305	6.902	2.813	1.540	2.668	0.000	1.073
hm	0.581	0.000	0.000	0.000	0.000	0.000	0.000	1.088	0.000	1.790	0.000
il	0.779	0.589	0.627	0.950	0.798	1.500	0.627	0.722	0.874	0.670	0.817
ap	0.185	0.301	0.255	0.324	0.232	0.440	0.185	0.255	0.417	0.220	0.370
py	0.000	0.000	0.000	0.150	0.094	0.000	0.075	0.019	0.000	0.000	0.094
Total	98.580	99.590	99.411	98.382	98.688	98.212	99.561	97.847	97.920	98.680	97.358

Rock Type	Rhyolitic Tuff										
Sample No.	U 1	U 3	U 7	U 7/1	U 7/2	U 10	U 10/1	U 11	U 13	P 30	P 31
Major element oxides (wt%)											
SiO_2	72.06	71.99	73.30	73.95	75.20	73.74	70.00	80.00	78.85	74.46	74.80
TiO_2	0.30	0.35	0.20	0.17	0.10	0.27	0.28	0.22	0.21	0.28	0.14
Al_2O_3	14.68	14.58	14.30	14.01	13.60	14.15	13.00	9.50	13.54	12.00	13.50
Fe_2O_3	1.92	2.25	1.20	0.90	0.30	1.30	4.73	0.01	0.26	0.90	2.19
FeO	0.36	0.32	1.83	0.46	0.64	0.63	0.27	0.28	0.78	1.76	0.18
MnO	0.01	0.03	0.20	0.03	0.00	0.01	0.07	0.00	0.01	0.11	0.07
MgO	0.10	0.20	0.80	0.42	0.10	0.62	0.35	0.15	0.21	0.69	0.14
CaO	0.18	0.27	0.90	0.23	0.01	1.26	0.96	0.02	0.02	1.66	0.11
Na^2O	4.59	5.83	3.70	3.99	0.77	1.78	2.60	0.00	0.03	3.50	2.94
K_2O	4.84	3.07	3.70	4.86	8.00	5.38	5.28	5.48	3.64	3.85	4.28
P_2O_5	0.03	0.06	0.03	0.02	0.01	0.06	0.05	0.04	0.02	0.04	0.03
S	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.01	0.09	0.01
H_2O^-	0.20	0.18	0.22	0.19	0.19	0.23	0.34	0.15	0.30	0.12	0.13
H_2O^+	0.37	0.53	0.84	0.58	0.77	0.82	3.77	1.38	1.95	0.52	0.63
CIPW norms											
Q	26.391	25.624	33.486	31.026	39.622	39.345	32.235	58.827	63.995	34.464	40.962
C	1.635	1.319	2.644	1.768	3.675	3.252	1.383	3.629	9.515	0.000	3.903
or	28.580	18.140	21.862	28.716	47.269	31.789	31.198	32.379	21.507	22.748	25.289
ab	38.839	49.332	31.308	33.762	6.516	15.062	22.000	0.000	0.254	29.616	24.877
an	0.697	0.948	4.269	1.141	0.000	5.859	4.436	0.000	0.099	5.663	0.350
di	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.923	0.000
hy-fs	0.000	0.000	2.411	0.000	0.742	0.000	0.000	0.110	0.869	1.524	0.000
hy-en	0.249	0.498	1.992	1.046	0.249	1.544	0.872	0.374	0.523	1.281	0.349
ol	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
mt	0.323	0.115	1.740	1.052	0.435	1.244	0.287	0.000	0.377	1.305	0.367
hm	1.697	2.171	0.000	0.175	0.000	0.442	4.532	0.000	0.000	0.000	1.937
il	0.570	0.665	0.380	0.323	0.190	0.513	0.532	0.418	0.399	0.532	0.266
ap	0.069	0.139	0.069	0.000	0.000	0.139	0.116	0.093	0.000	0.093	0.069
py	0.000	0.000	0.000	0.019	0.019	0.019	0.000	0.037	0.190	0.168	0.019
Total	98.069	98.950	100.162	99.027	98.716	99.207	97.590	95.704	97.557	98.387	96.809

Rock Type	Diorite						Granodiorite			Granite		
Sample No.	N 1	N 15	N 19	N 20	P 28	P 29	N 17	N 18/1	P 3	P 4	P 5	P 27
Major element oxides (wt%)												
SiO_2	54.15	53.10	52.10	52.50	50.00	61.00	74.52	75.26	65.81	74.13	74.23	72.80
TiO_2	0.68	0.61	2.00	0.68	1.67	1.28	0.32	0.30	0.92	0.29	0.31	0.29
Al_2O_3	15.74	18.00	15.14	16.50	15.00	15.50	12.90	12.65	14.28	14.37	12.97	12.90
Fe_2O_3	4.25	3.24	7.65	3.72	3.77	3.02	0.91	1.73	3.22	1.42	1.18	1.53
FeO	5.92	4.25	4.63	6.43	6.54	3.18	1.17	0.73	1.70	0.48	0.77	0.28
MnO	0.18	0.12	0.16	0.21	0.12	0.15	0.05	0.07	0.09	0.03	0.04	0.01
MgO	5.02	6.00	3.92	4.60	6.37	1.98	0.55	0.75	1.00	0.12	0.24	0.29
CaO	8.34	5.50	6.50	8.40	10.00	3.26	2.10	2.65	2.33	0.57	0.81	0.68
Na_2O	1.97	4.90	3.55	2.60	3.45	4.95	4.68	3.90	4.28	4.71	4.60	5.22
K_2O	1.20	0.75	1.85	1.00	0.78	3.60	0.90	1.02	4.16	3.63	4.13	4.57
P_2O_5	0.17	0.12	0.85	0.18	0.40	0.46	0.04	0.05	0.21	0.04	0.04	0.03
S	0.01	0.00	0.00	0.02	0.05	0.01	0.00	0.02	0.00	0.01	0.00	0.02
H_2O^-	0.23	0.18	0.07	0.16	0.15	0.15	0.12	0.10	0.22	0.26	0.23	0.28
H_2O^+	2.45	3.21	1.60	2.25	1.10	0.86	1.74	0.74	0.98	0.48	0.44	0.58
CIPW norms												
Q	12.337	0.000	8.462	7.757	0.000	9.919	38.210	42.017	19.693	31.556	29.550	24.578
C	0.000	0.000	0.000	0.000	0.000	0.000	0.505	0.432	0.000	1.752	0.000	0.000
or	7.090	4.431	10.931	5.909	4.609	21.271	5.318	6.027	24.580	21.448	24.403	27.003
ab	16.670	41.462	30.039	22.000	29.293	41.886	39.601	33.001	36.216	39.855	38.924	40.913
an	30.562	24.905	19.913	30.398	23.139	9.443	10.157	12.820	7.468	2.567	2.546	0.000
di	7.867	1.276	5.282	8.258	19.197	2.981	0.000	0.000	2.118	0.000	0.944	1.558
hy-fs	5.239	3.972	0.000	6.304	3.094	1.159	0.961	0.000	0.000	0.000	0.001	0.000
hy-en	9.999	13.664	7.314	9.072	7.843	3.837	1.370	1.868	1.509	0.299	0.161	0.000
ol	0.000	1.493	0.000	0.000	2.813	0.000	0.000	0.000	0.000	0.000	0.000	0.000
mt	6.162	4.698	9.648	5.394	5.466	4.379	1.319	1.639	3.106	0.768	1.711	0.220
hm	0.000	0.000	0.996	0.000	0.000	0.000	0.000	0.599	1.078	0.890	0.000	0.523
il	1.291	1.159	3.798	1.291	3.172	2.431	0.608	0.570	1.747	0.551	1.589	0.551
ap	0.394	0.278	1.968	0.417	0.926	1.065	0.093	0.116	0.486	0.093	0.093	0.669
py	0.019	0.000	0.000	0.037	0.094	0.019	0.000	0.037	0.000	0.019	0.000	0.370
Total	97.629	97.338	98.351	96.837	99.545	98.389	98.452	99.125	98.000	99.797	99.320	98.614

Table 4.2 Trace element analyses and elemental ratios

Rock Type	Andesite							
Sample No.	U 6	N 14	N 16	N 18	T 24/1	T 26	P 8	P 31/1
Trace element (ppm)								
Zr	168	158	93	44	83	62	72	170
Nb	43	40	30	36	44	35	36	36
Sr	652	827	376	161	122	114	68	464
Rb	13	10	10	10	10	152	10	10
Pb	23	17	19	20	19	24	19	16
Zn	79	111	90	79	151	232	231	85
Ta	43	20	34	39	27	17	33	19
Ba	101	58	63	31	45	102	47	73
Elemental ratios								
K/Rb	530.00	747.13	232.44	58.11	597.70	410.16	556.20	398.47
Ba/Rb	7.77	5.80	6.30	3.10	4.50	0.67	4.70	7.30
K/Ba	67.40	12.88	36.89	18.74	132.82	611.22	118.34	54.58
Ca/Sr	76.73	62.05	121.65	408.40	391.91	290.26	836.61	144.79
Rb/Sr	0.02	0.01	0.03	0.06	0.08	1.33	0.15	0.02
Zn/Pb	3.43	6.53	4.74	3.95	7.95	9.67	12.16	5.31

Rock Type				Dacite		Dacite-Rhyolite			Rhyolite		
Sample No.	T 1	T 3	T 5	T 10	T 25	P 7	P 9	T 22	T 22/1	T 23	T 23/1
Trace element (ppm)											
Zr	134	165	140	116	166	127	137	126	149	120	141
Nb	60	53	58	56	58	44	55	52	58	56	54
Sr	225	110	336	154	220	213	165	88	104	63	138
Rb	60	98	75	10	140	16	76	89	92	119	104
Pb	27	28	27	26	26	22	29	26	26	27	25
Zn	73	57	85	75	80	103	79	59	78	42	63
Ta	95	86	86	71	65	42	85	69	58	72	60
Ba	148	129	145	85	111	79	68	145	166	130	170
Elemental ratios											
K/Rb	390.17	224.48	280.04	846.75	168.99	425.45	168.21	387.09	375.37	306.94	255.43
Ba/Rb	2.47	1.32	1.93	8.50	0.79	4.94	0.89	1.63	1.80	1.09	1.63
K/Ba	158.18	170.53	144.85	99.62	213.15	86.17	188.00	237.59	208.04	280.97	156.26
Ca/Sr	63.21	67.57	21.91	92.82	97.78	181.19	93.13	172.18	83.84	14.75	166.24
Rb/Sr	0.27	0.89	0.22	0.06	0.64	0.08	0.46	1.01	0.88	1.89	0.75
Zn/	2.70	2.04	3.15	2.88	3.08	4.68	2.72	2.27	3.00	1.56	2.52

Rock Type	Rhyolitic Tuff										
Sample No.	U 1	U 3	U 7	U 7/1	U 7/2	U 10	U 10/1	U 11	U 13	P 30	P 31
Trace element (ppm)											
Zr	265	267	175	150	147	131	203	136	211	331	265
Nb	63	69	59	63	61	59	55	56	66	68	71
Sr	104	249	275	51	64	23	10	10	29	102	55
Rb	223	173	206	220	250	245	194	166	259	102	134
Pb	30	30	30	29	30	28	27	33	33	48	29
Zn	92	71	70	72	32	43	64	38	49	90	128
Ta	79	82	86	81	86	70	67	89	85	59	79
Ba	153	143	153	149	452	82	96	141	44	172	133
Elemental ratios											
K/Rb	172.44	147.32	149.10	183.40	265.65	182.29	228.93	274.05	116.67	313.34	265.15
Ba/Rb	0.66	0.83	0.74	0.68	1.81	0.33	0.49	0.85	0.17	1.69	0.99
K/Ba	262.60	178.22	200.75	270.77	146.93	544.66	456.58	322.64	686.76	185.22	267.14
Ca/Sr	12.37	7.75	23.39	32.23	1.12	391.53	686.11	14.29	4.93	116.31	14.29
Rb/Sr	2.24	0.69	0.75	4.31	3.91	10.65	19.40	16.86	0.86	1.00	2.44
Zn/Pb	3.07	2.37	2.33	2.48	1.07	1.54	2.37	1.15	1.48	1.88	4.41

Rock Type	Diorite						Granodiorite			Granite		
Sample No.	N 1	N 15	N 19	N 20	P 28	P 29	N 17	N 18/1	P 3	P 4	P 5	P 27
Trace element (ppm)												
Zr	58	78	58	43	189	307	143	107	658	300	305	259
Nb	30	48	32	41	42	59	60	52	59	66	55	72
Sr	244	566	282	305	352	196	101	135	93	59	53	95
Rb	10	10	10	10	10	69	72	48	70	75	106	122
Pb	19	22	17	19	17	21	28	29	24	29	29	27
Zn	98	87	79	107	19	75	54	52	71	56	52	37
Ta	29	48	18	24	15	40	90	86	66	87	90	76
Ba	74	51	94	68	64	129	54	65	129	107	106	80
Elemental ratios												
K/Rb	996.18	622.61	1535.77	830.15	647.52	433.12	103.77	176.41	493.34	401.79	323.44	310.96
Ba/Rb	7.40	5.10	9.40	6.80	6.40	1.87	0.77	1.35	1.84	1.43	1.00	0.66
K/Ba	134.62	122.08	163.38	122.08	101.17	231.67	138.36	130.27	267.71	281.63	323.44	474.22
Ca/Sr	244.28	69.45	164.73	196.83	203.04	118.87	148.60	140.29	179.06	69.05	109.23	51.16
Rb/Sr	0.04	0.02	0.34	0.03	0.03	0.35	0.71	0.35	0.75	1.27	2.00	1.28
Zn/Pb	5.16	3.95	4.65	5.63	1.12	3.57	1.93	1.79	2.96	1.93	1.79	1.37

Key to table 4.1 and 4.2

U 6	= Andesite of U-Thai Thani area
N 14, N 16, N 18	= Andesite of Nakhon Sawan area
T 24/1, T 26	= Andesite of Tha Tako area
P 8, P 31/1	= Andesite of Phai Sali area
T 1, T 3, T 5, T 10, T 25	= Dacite of Tha Tako area
P 7, P 9	= Dacite of Phai Sali area
T 22, T 22/1, T 23, T 23/1	= Rhyolite of Tha Tako area
U 1, U 3, U 7, U 7/1, U 7/2	= Rhyolitic tuff of U-Thai Thani area
U 10, U 10/1, U 11, U 13	
P 30, P 31	= Rhyolitic tuff of Phai Sali area
N 1, N 15, N 19, N 20	= Diorite of Nakhon Sawan area
P 28, P 29	= Diorite of Phai Sali area
N 17, N 18/1	= Granodiorite of Nakhon Sawan area
P 3	= Granodiorite of Phai Sali area
P 4, P 5, P 27	= Granite of Phai Sali area
q	= normative quartz
c	= normative corundum
or	= normative orthoclase
ab	= normative albite
an	= normative anorthoclase
di	= normative diopside
hy-fs	= normative hypersthene
hy-en	= normative enstatite
ol	= normative olivine

mt	=	normative magnetite
hm	=	normative hematite
il	=	normative hematite
ap	=	normative apatite
py	=	normative pyrite

Table 4.3 Chemical Parameter

Rock Type	Andesite							
Sample No.	U 6	N 14	N 16	N 18	T 24/1	T 26	P 8	P 31/1
Mafic index	70.92	71.76	71.60	62.97	77.05	74.42	69.39	69.93
Felsic index	37.61	30.76	44.49	9.54	41.11	64.82	33.67	33.62
Differentiation index	48.16	43.52	49.74	30.02	51.12	63.26	45.22	45.08
Solidification index	20.22	23.44	21.21	34.76	16.60	12.31	18.04	22.84

	Dacite-Rhyolite										
Rock Type	Dacite							Rhyolite			
Sample No.	T 1	T 3	T 5	T 10	T 25	P 7	P 9	T 22	T 22/1	T 23	T 23/1
Mafic index	84.52	81.55	79.62	86.83	83.07	85.64	86.92	85.34	74.44	94.09	74.78
Felsic index	78.69	88.38	88.48	74.72	69.93	43.28	70.75	79.56	88.26	98.37	72.70
Differentiation index	88.28	88.35	88.71	76.10	74.60	60.78	81.04	87.65	85.05	96.04	79.85
Solidification index	3.95	5.92	6.53	7.17	7.07	15.24	6.69	4.29	7.97	1.29	8.77

Rock Type	Rhyolitic tuff										
Sample No.	U 1	U 3	U 7	U 7/1	U 7/2	U 10	U 10/1	U 11	U 13	P 30	P 31
Mafic index	95.80	92.78	79.11	76.40	90.38	75.69	93.46	65.91	83.20	79.40	94.42
Felsic index	98.13	97.06	89.16	97.47	99.89	85.04	89.14	99.64	99.46	81.58	98.50
Differentiation index	94.71	94.08	86.52	94.42	94.62	86.88	87.54	95.30	87.90	87.42	92.62
Solidification index	0.85	1.71	7.12	3.95	1.05	6.38	2.64	2.53	4.27	6.45	1.44

Rock Type	Diorite						Granodiorite			Granite		
Sample No.	N 1	N 15	N 19	N 20	P 28	P 29	N 17	N 18/1	P 3	P 4	P 5	P 27
Mafic index	77.15	55.52	75.80	68.81	61.81	75.79	79.09	76.64	83.11	97.05	94.84	86.19
Felsic index	27.54	55.62	45.38	30.00	29.72	72.40	72.66	64.99	78.36	93.60	91.51	93.50
Differentiation index	36.97	47.15	50.26	36.83	33.96	74.27	84.70	81.76	82.13	93.05	93.92	93.79
Solidification index	27.34	31.35	18.15	27.05	30.46	11.84	6.70	9.22	6.96	1.16	2.20	2.44

Mafic index (M.I.) = $100\,(FeO+Fe_2O_3)/(FeO+Fe_2O_3+MgO)$

(Wagner and Deer, 1939)

Felsic index (F.I.) = $100\,(Na_2O+K_2O)/(CaO+Na_2O+K_2O)$

(Simpson, 1954)

Differentiation index (D.I.) = normative Q+Or+Ab+Ne+Ks+Lc

(Thornton and Tuttle, 1960)

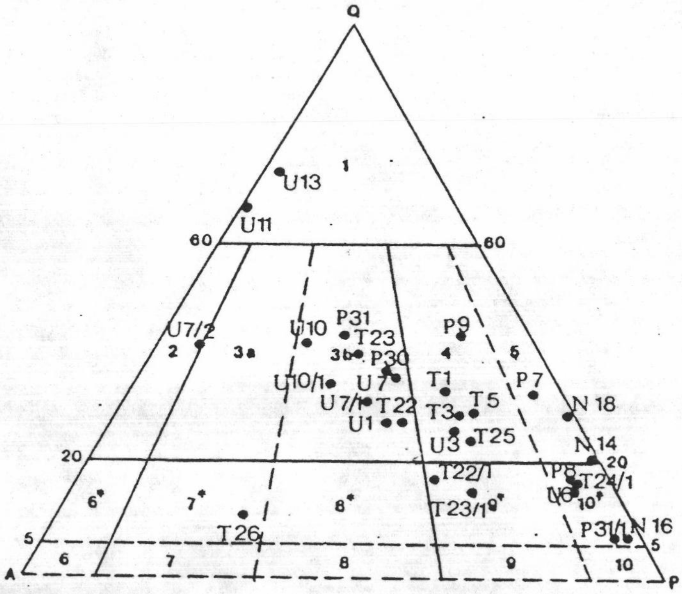
Solidification index (S.I.) = $100\,MgO/\,(MgO+FeO+Fe_2O_3+Na_2O+K_2O)$

(Kuno, 1969)

microcrystalline or cryptocrystalline or even glassy texture of the groundmass. Therefore classification and nomenclature of these volcanic rocks are based purely on chemical criteria of these rocks. Normative quartz, potash feldspar, and plagioclase calculated from major oxides of the rocks are plotted in triangular QAP diagram as suggested by IUGS Subcommission (Streckeisen, 1979). Supplement method for classification of volcanic rocks by plotting $Na_2O + K_2O$ vs SiO_2 in a pentagon diagram proposed by Cox et al. (1979) is also used in order to compare their outcomes. Figure 4.1(Streckeisen, 1979) and Figure 4.2 (Cox et al., 1979) show that majority of specimens are coincident in rock classification. It is also clearly shown from both figures that the volcanic rocks from the study area range in composition from andesite to dacite and rhyolite. There are only few samples that are variant from this compositional trend.

The volcanic and the associated plutonic rocks are designated to be rocks of calc-alkalic series by using method proposed by Kuno in 1959 (Figures 4.3 and 4.4). Variation diagrams of the major element-oxides plotted against silica oxide (Figure 4.5) appear to show common distinct trend between the plutonic and the volcanic rocks.

SiO_2: The ranges of the SiO_2 content of each rock type are relative restricted. The SiO_2 content of rhyolite ranges from 65.20 to 75.00 %, of rhyolitic tuff from 70.00 to 80.00 %, of dacite from 63.14 to 74.09 %, of andesite from 51.60 to 59.57 %, of granite from 72.80 to 74.23 %, of granodiorite from 65.81 to 75.26 %, and of diorite from 50.00 to 61.00 %.



ROOT NAMES

2	alkali (-feldspar) rhyolite (liparite) (see text)
3a 3b	rhyolite (liparite) (see text)
4 5	dacite (see text)
6*	quartz-alkali (-feldspar) trachyte
6	alkali (-feldspar) trachyte
6'	foid-bearing alkali (-feldspar) trachyte
7*	quartz trachyte
7	trachyte
7'	foid-bearing trachyte
8*	quartz latite
8	latite
8'	foid-bearing latite
9 10	andesite, basalt (see text)

GROUP NAMES

Fields		
2, 3a, 3b	I	rhyolitoids
4, 5	II	dacitoids
6, 7, 8	III	trachytoids
9, 10	IV	**andesitoids, basaltoids**

Fig. 4.1 Recommended names of volcanic rocks and their fields in QAP diagram. (Streckeisen, 1979)

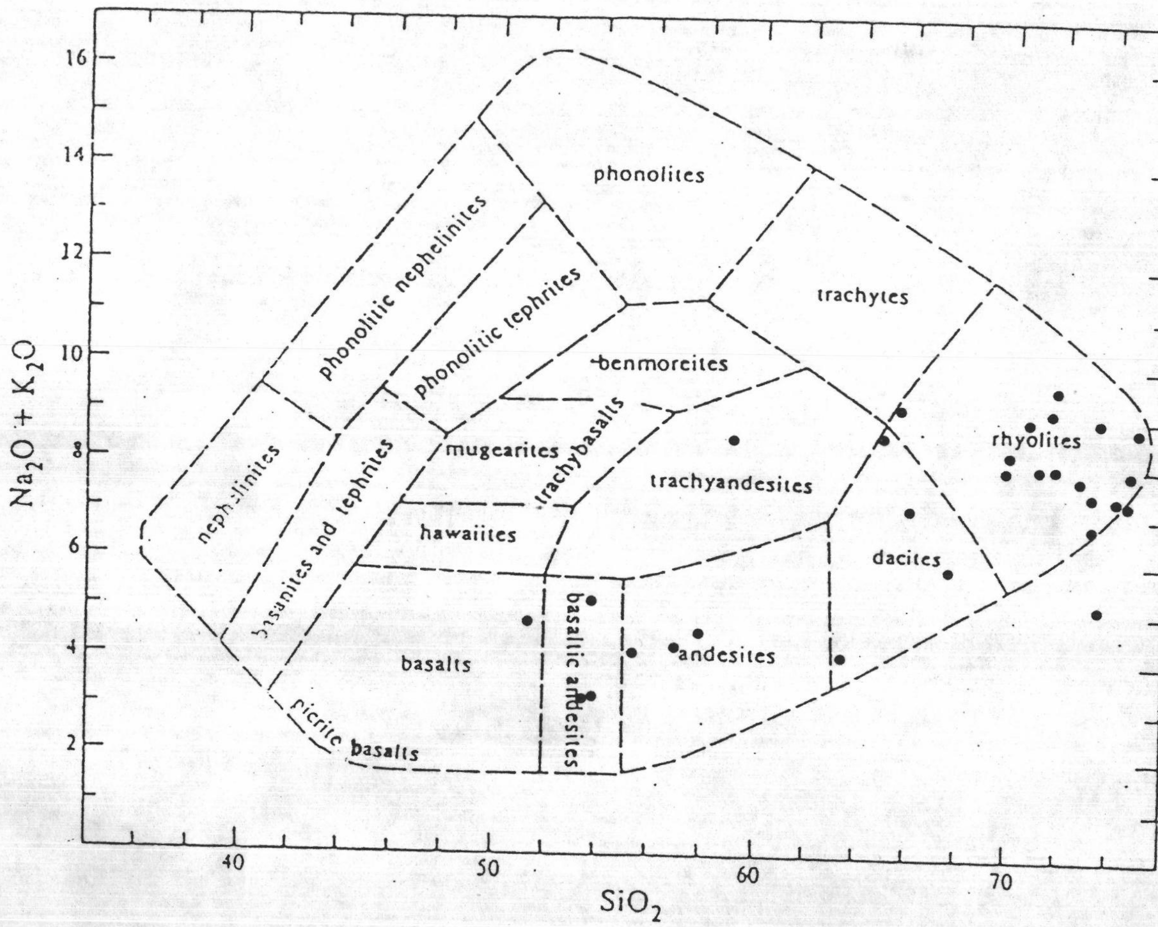


Fig. 4.2 Plots of $Na_2O + K_2O$ against SiO_2 for the volcanic rocks of Nakhon Sawan and U-Thai Thani area. Nomenclature and boundaries of volcanic rocks are from Cox et al (1979).

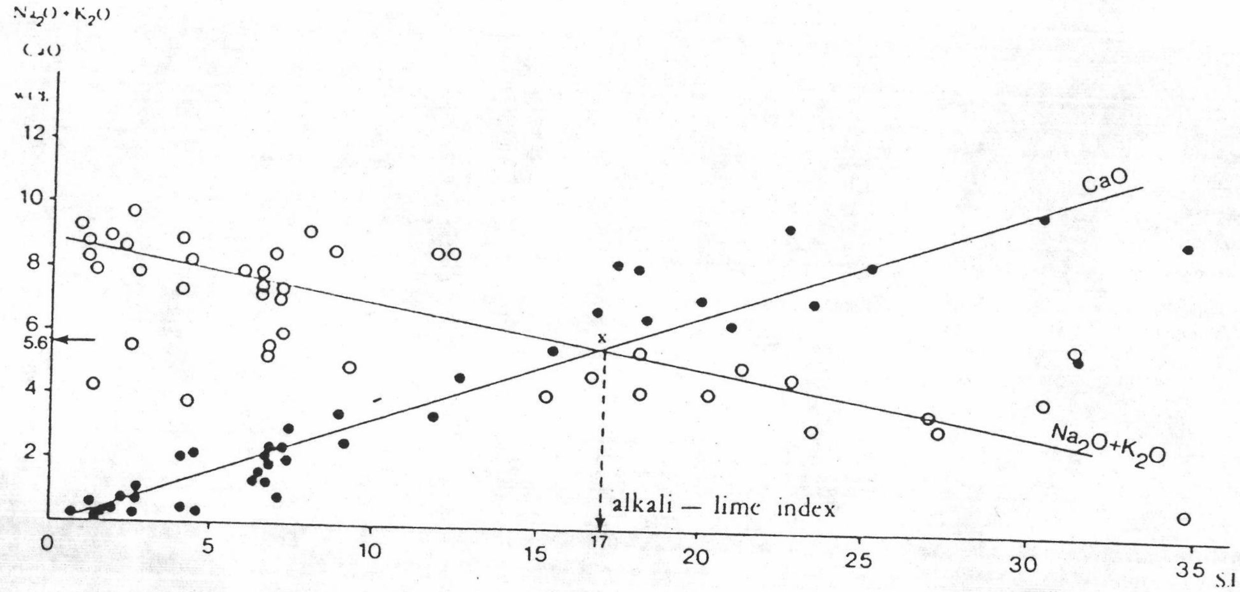


Fig. 4.3 Plots of (Na_2O+K_2O), CaO against solidification index leading to alkali-lime index of volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

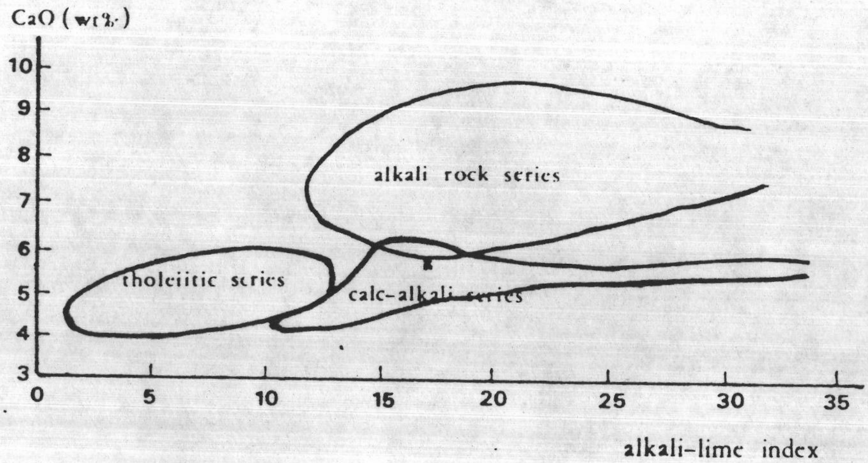


Fig. 4.4 Plots of alkali-lime index against CaO giving a good separation of rocks into tholeiitic series, alkali rock series, and calc-alkali rock series (after Kuno, 1959)

Al_2O_3 : The Al_2O_3 content shows relatively unchanged when the content of SiO_2 increases. It is in the uniform range from intermediate to acid rock.

TiO_2, FeO, Fe_2O_3, CaO, MgO : The TiO_2, FeO, Fe_2O_3, CaO and MgO contents decrease sharply when the rocks change in composition from intermediate to silicic ones.

MnO and Na_2O : The MnO and Na_2O contents of these rocks do not exhibit clear correlation with the SiO_2 content. However, the Na_2O content seems to increase and the MnO content tends to decrease as the silica content increases.

K_2O : The K_2O content increases distinctively with increasing SiO_2 content. However, the K_2O contents of rhyolite, rhyolitic tuff, and granite do not exhibit a clear trend. They rather appear to be scattered.

P_2O_5 : The P_2O_5 content shows slightly decrease from andesite to rhyolite, rhyolitic tuff, and granite. The P_2O_5 content of diorite appear to be scattered.

In solidification diagrams (Figure 4.6), standard major oxides are plotted against the percentage of the solidification index (S.I) which is the product of MgO x 100/MgO + Fe_2O_3 + Na_2O + K_2O. The SI index should decrease with increasing differentiation (Kuno, 1969). The additional variation diagrams of plots of other major oxides against MgO are presented in Figure 4.7 . The characteristic features of these two types of variation diagrams are quite similar, namely, the SiO_2 and K_2O contents increase and P_2O_5, FeO + Fe_2O_3, TiO_2,

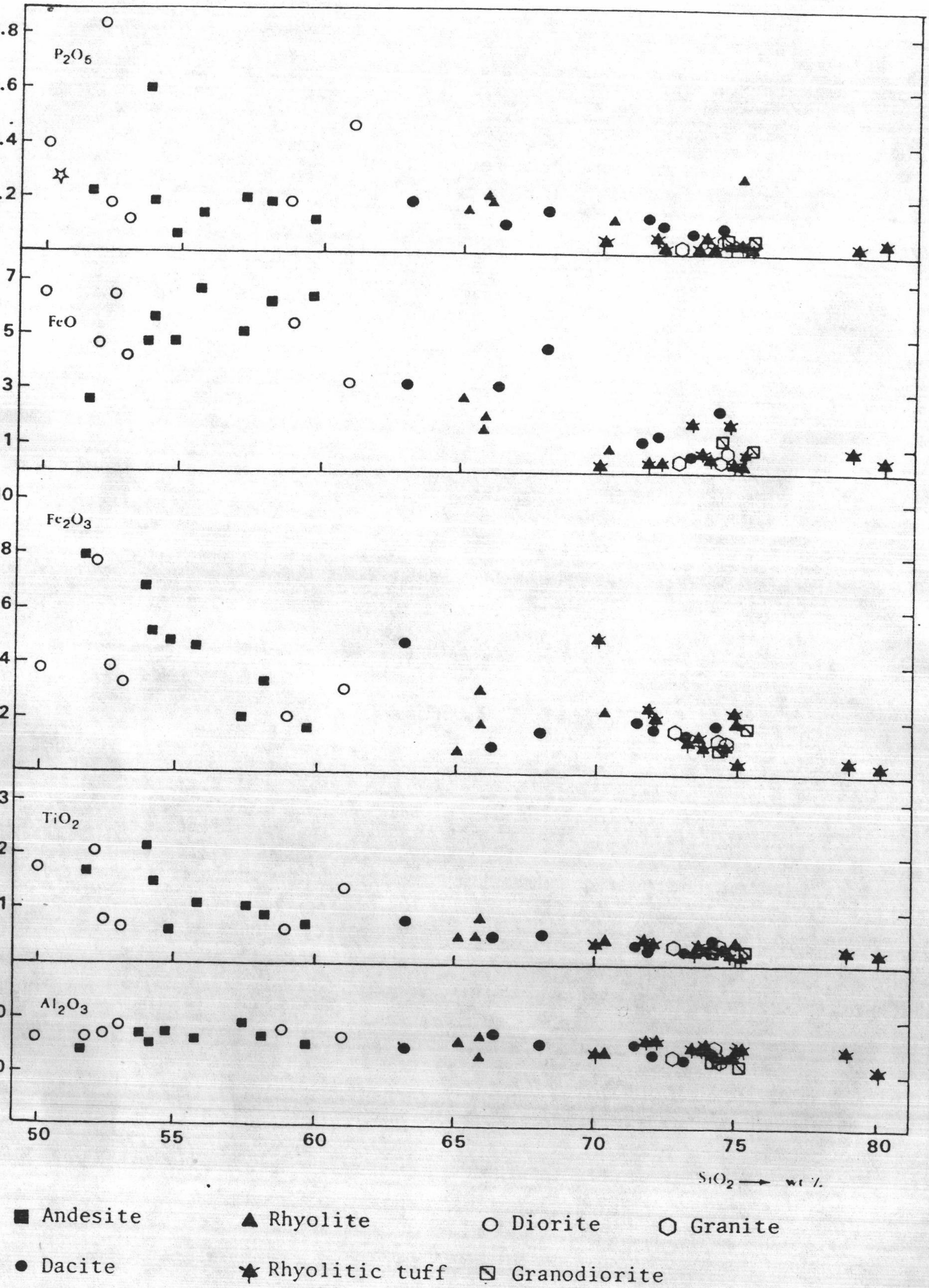


Fig. 4.5 Variation of major element-oxides against silica for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

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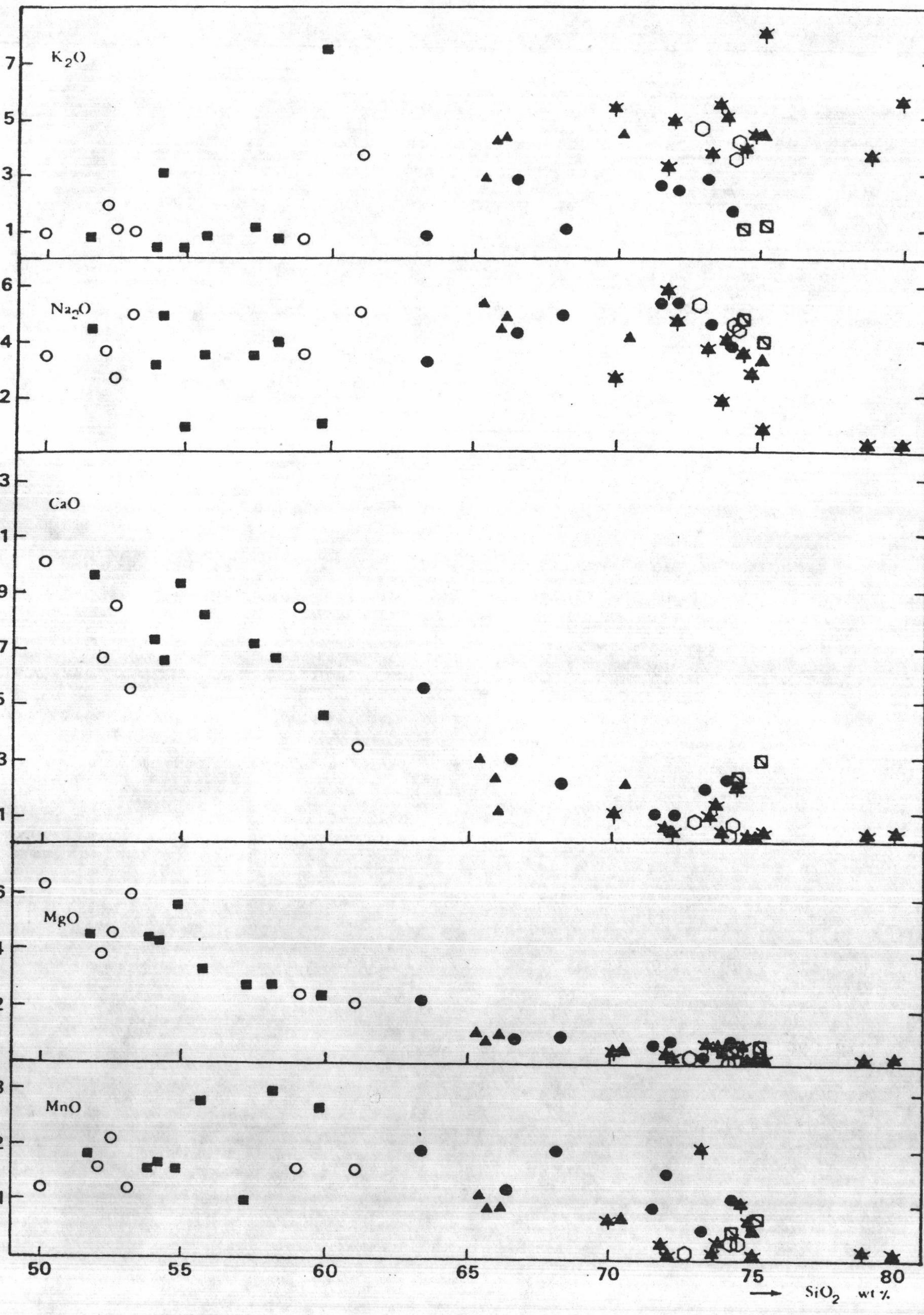

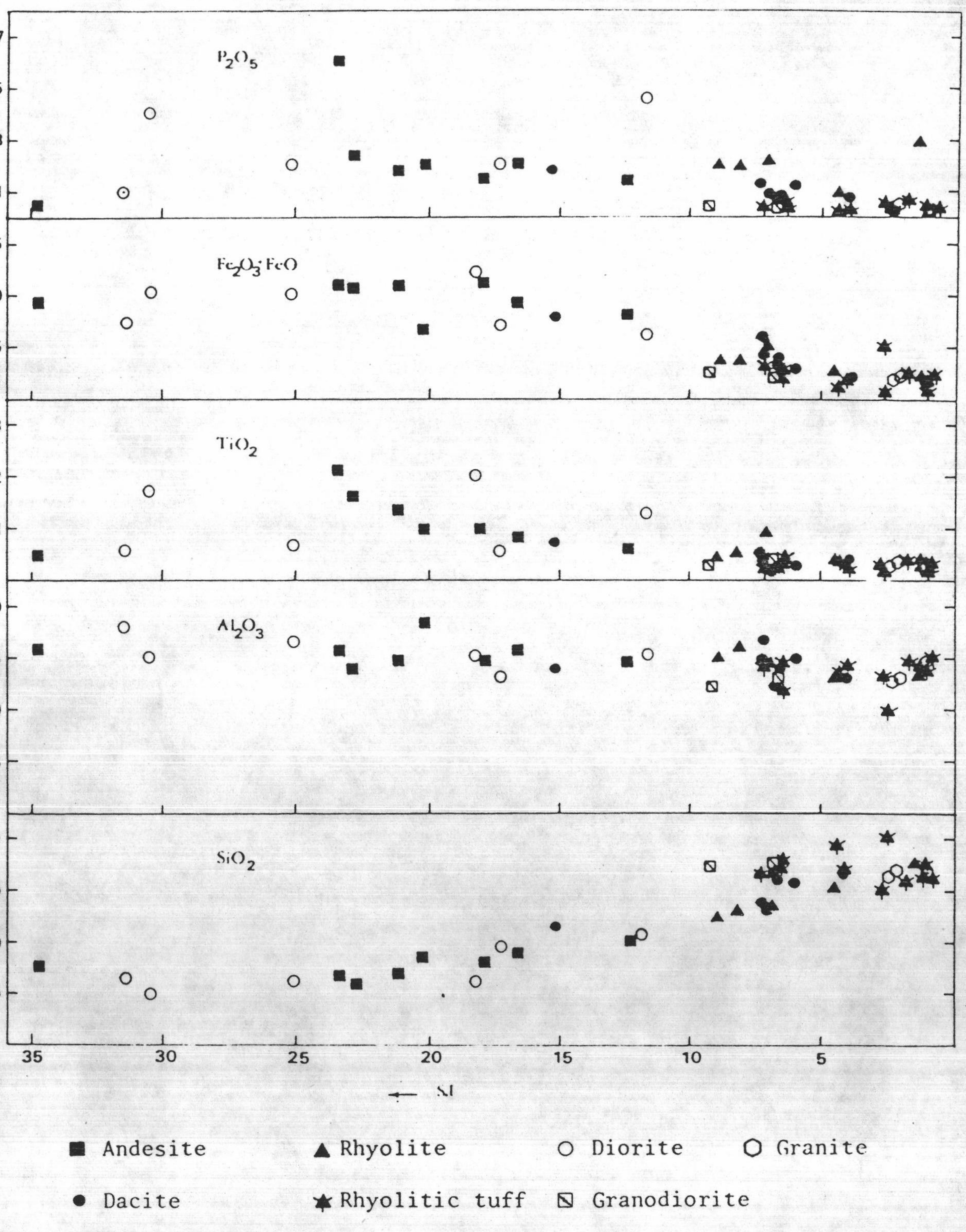

Fig. 4.6 Variation of major element-oxides against SI for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

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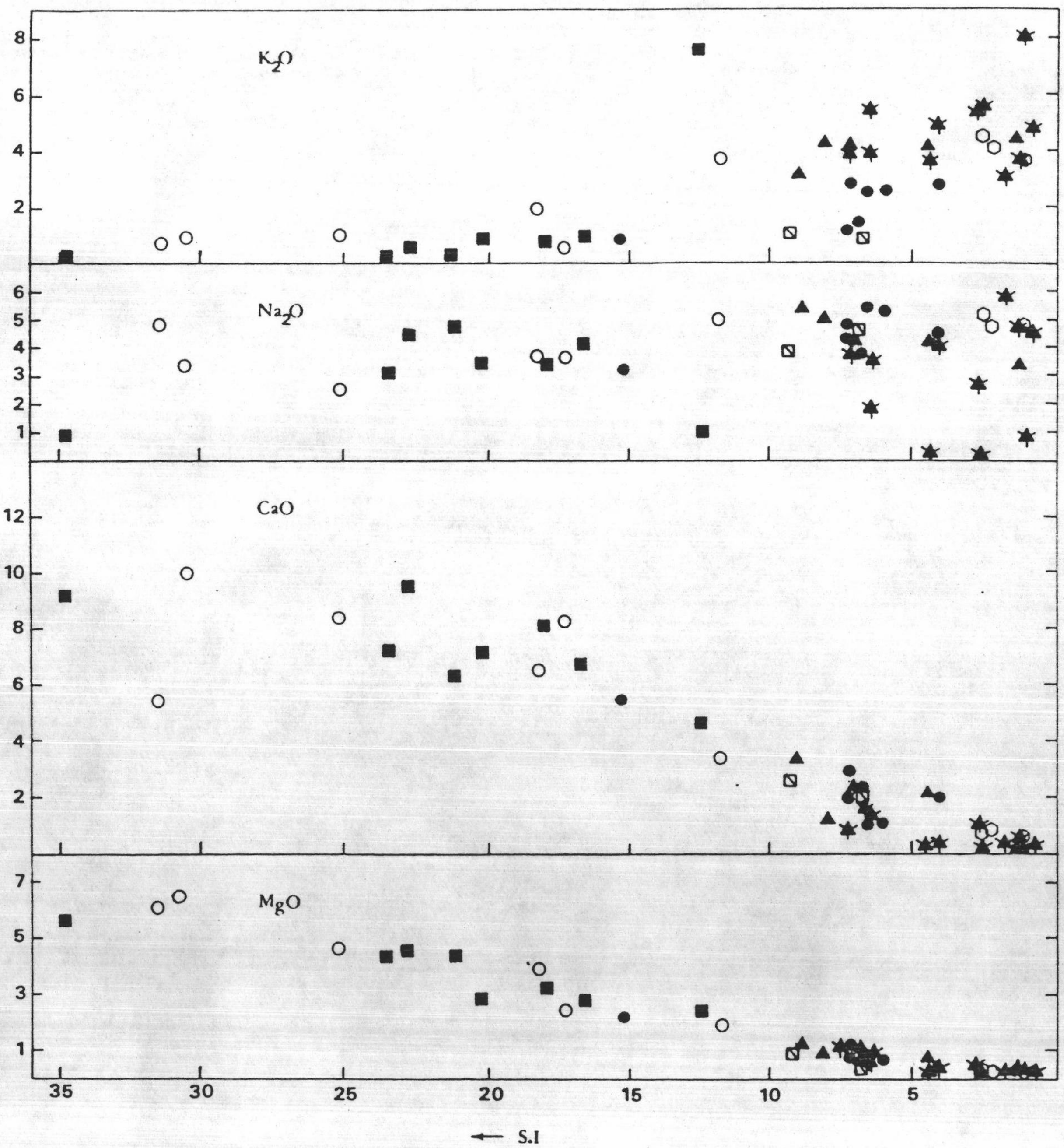

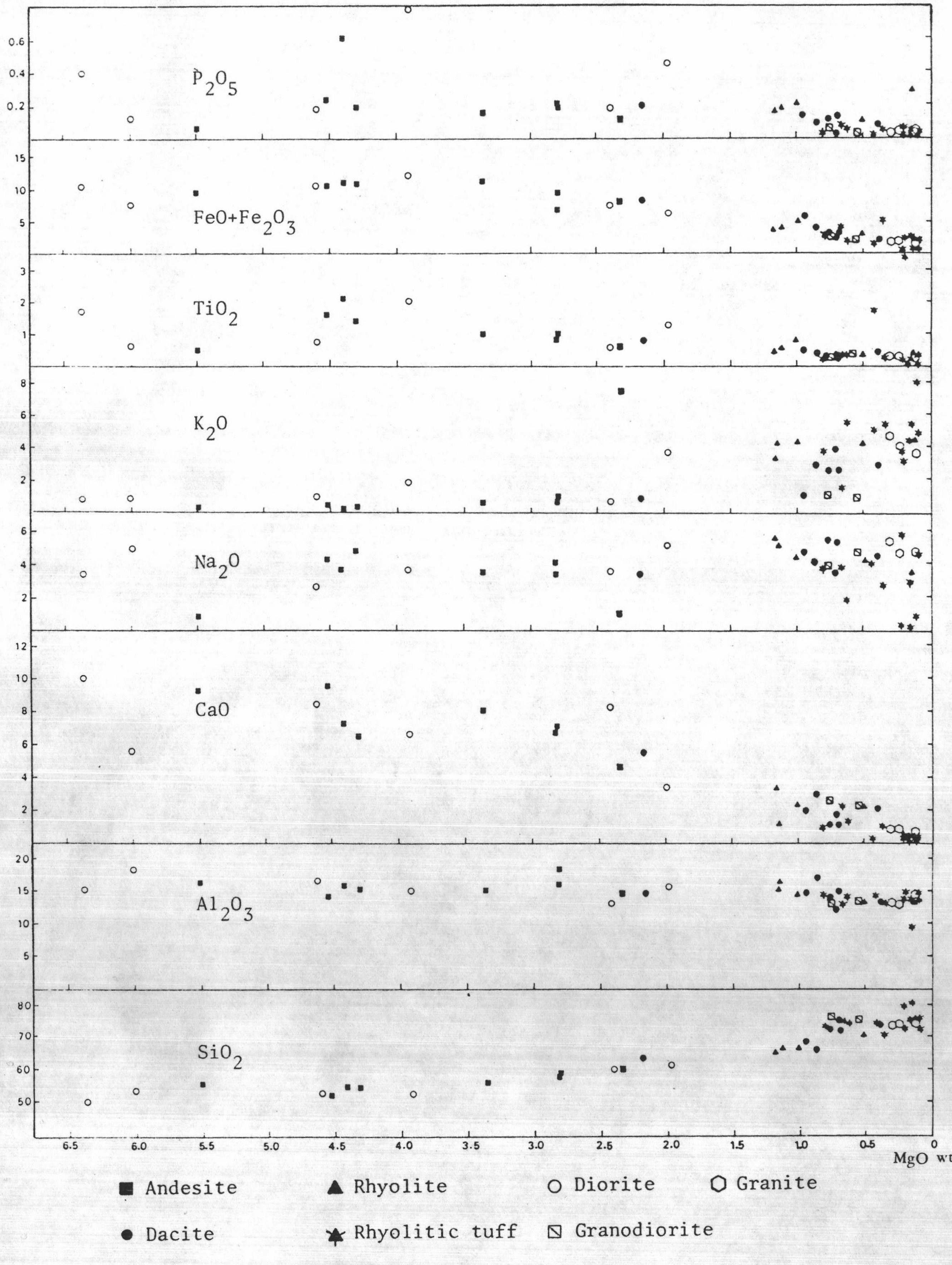

Fig.4.7 Variation of major element-oxides against MgO for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

Cao, and MgO contents decrease with decreasing in the number of SI and MgO : The Al_2O_3 and Na_2O contents seem to be unchanged throughout the differentiation stages.

The ratio of Na_2O + K_2O : FeO* : MgO of the plutonic and volcanic rocks are plotted in the AFM triangular diagram as show in Figure 4.8 (= FeO + 0.9 Fe_2O_3). Differentiation trends of Asama, Amagi, Skaergaard, Miyake-jima, Macualey, and Tofua are also shown in this diagram for comparison. The Asama and Amagi are the differentiation trends of calc-alkaline series whereas the Skaergaard, Miyake-jima, Macualey, and Tofua are those of tholeiitic series (Miyashiro, 1974). In such diagram, the early and middle-stage of crystallization of typical tholeiitic series are represented by curves approximately parallel to the MgO - FeO* sideline, and in the late stage, a sharp turn occurs toward the Na_2O + K_2O corner to indicate more silicic rocks. In contrast, rocks of typical calc-alkaline series show trends nearly perpendicular to the MgO - FeO* sideline. Plots of the plutonic and volcanic rocks in the AFM diagram show considerably good alignment and are conformable with the Asama and Amagi trends of Japanese calc-alkaline series (Miyashiro, 1974). This trend starts up near the MgO - FeO* sideline with moderate iron concentration. The FeO and MgO decrease gradually in the later stage with contemporaneous increasing in the Na_2O + K_2O contents.

When the alkalinity ratio (Al_2O_3 + CaO + K_2O + Na_2O/Al_2O_3 + CaO - (K_2O + Na_2O)) (Wright, 1969) is plotted against the SiO_2 content, the majority of samples fall in a typical calc-alkaline field affinity. There are only few samples become more alkaline with increasing SiO_2

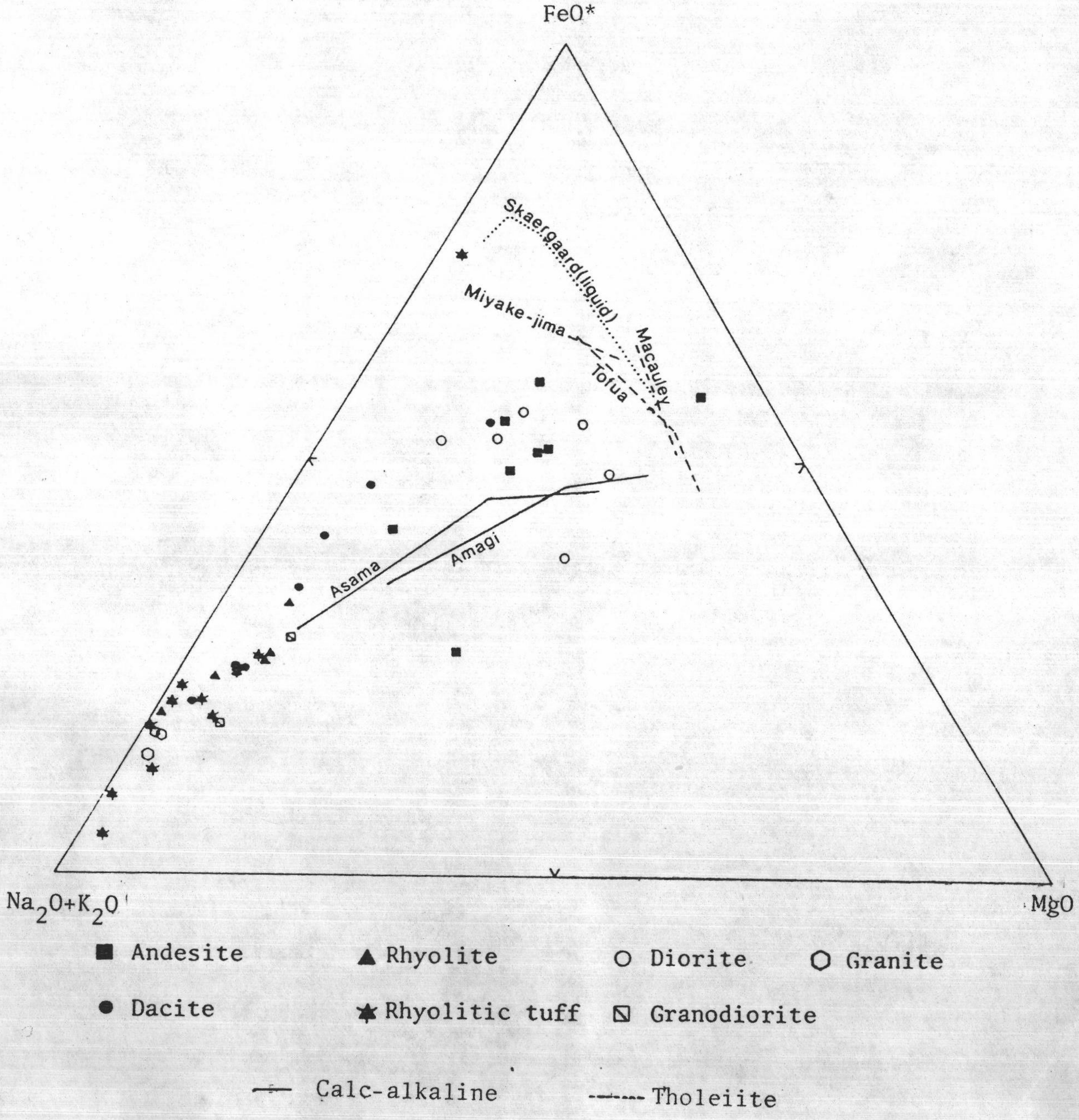

Fig. 4.8 AFM diagram of volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area (Miyashiro, 1974)

content. This appears to be general characteristic of many calc-alkaline associations (Sheraton and Labonne, 1978) (Figure 4.9).

Graph of K_2O versus SiO_2 can be used to distinguish three types of volcanic series, namely, tholeiite, calc-alkaline and alkaline. General boundary lines separate fields of rock suites and rock types are first proposed by Peccerillo and Taylor (1976) and later modified by Innocenti, Monetti, Mazzuoli and Pasquaré (1982). The K_2O content of rock samples from the study area varies widely ranging from 0.09 to 8.0 percent and the SiO_2 content ranges from 45.62 to 80.0 percent. Graph of K_2O plotted against SiO_2 (Figure 4.10) illustrates that rhyolite, rhyolitic tuff, dacite, and granite are relatively higher in K_2O content than andesite, granodiorite, and diorite and accordingly attributed to the high K calc-alkaline series and calc-alkaline series (boundaries II and III).

4.2 Trace Element Variations

Variation diagrams constructed from plots of the trace elements against SiO_2 (Figure 4.11) show that with increasing SiO_2 content the Rb and Ta contents increase sharply, the Nb, Ba, and Pb contents increase gradually, Zr content increases slightly, Sr content decreases sharply and Zn content decreases slightly.

Some selected elemental ratios i.e., K/Rb, Ba/Rb, K/Ba, Ca/Sr and Rb/Sr are plotted against SiO_2 content as shown in Figure 4.12. From the plotting of these silica variation diagram, the K/Rb and Ba/Rb ratios decrease with an increasing of the SiO_2 content. The ratio content of the K/Ba increases while the Rb/Sr slightly increases with an increasing of the SiO_2 content. The Ca/Sr ratio shows unchanged amounts as the SiO_2 content increases.

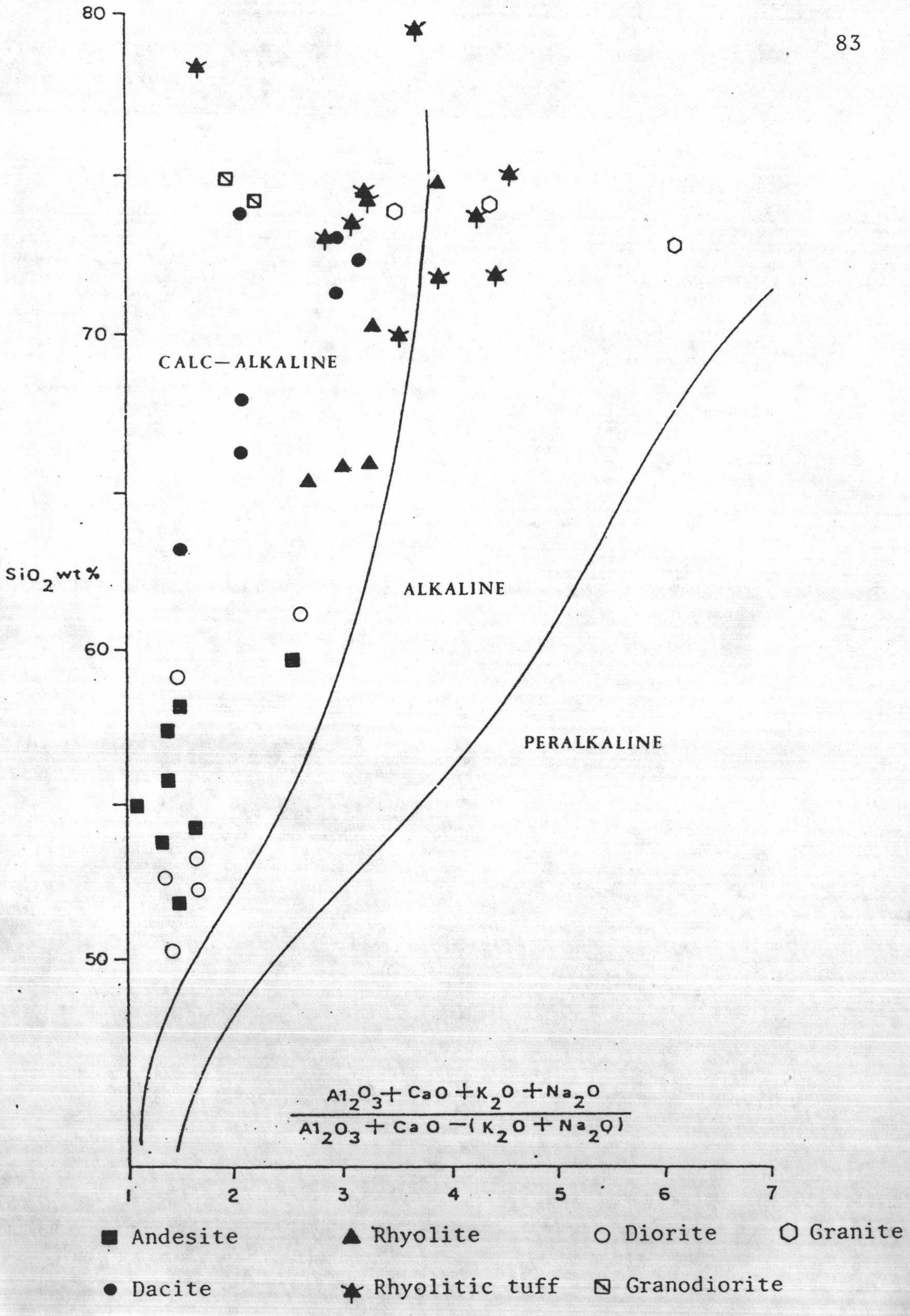

Fig. 4.9 Alkalinity ratio variation diagram for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area. The alkalinity fields are from Wright (1969, cited in Sheraton and Labonne, 1978).

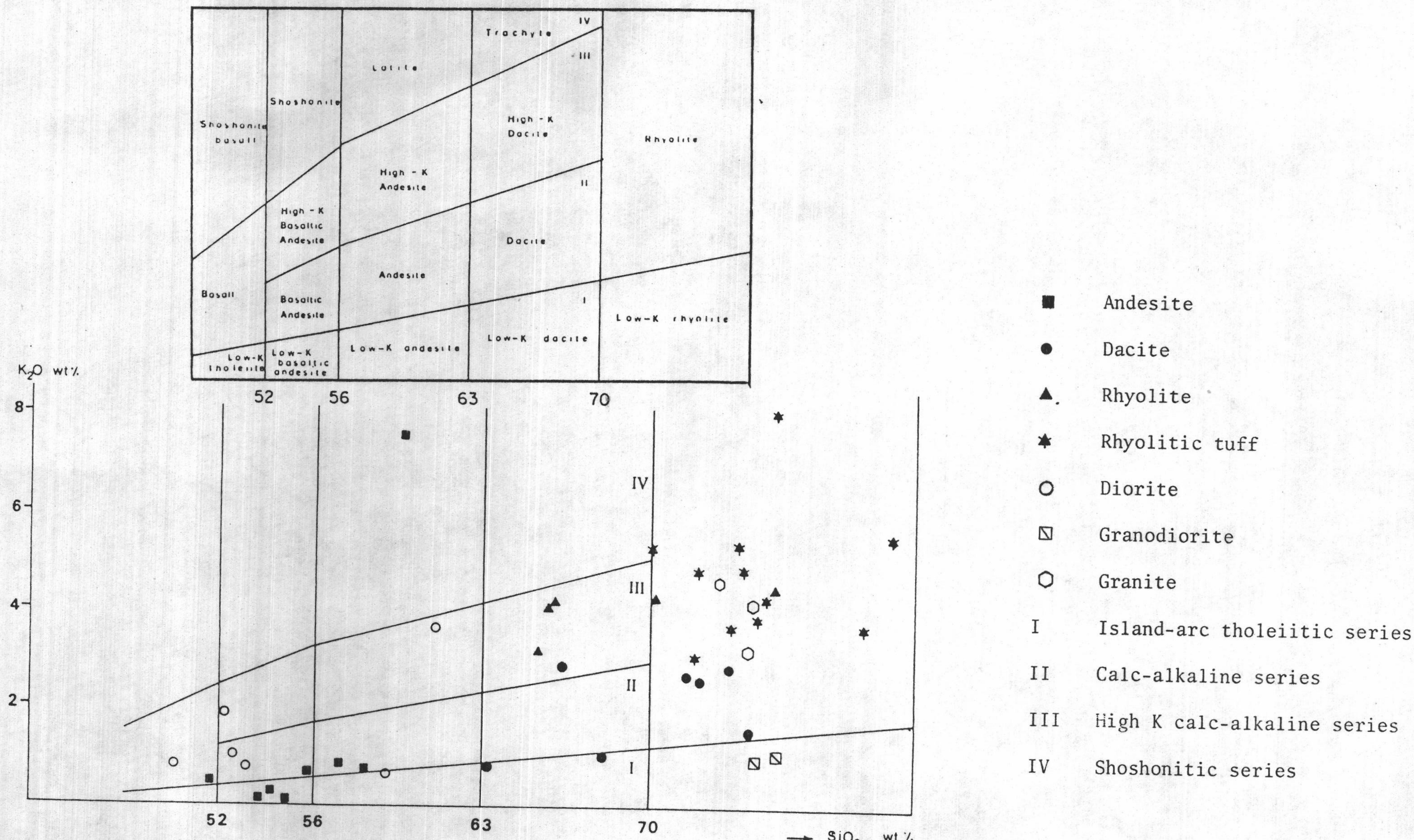

Fig.4.10 Graphs of K_2O versus SiO_2 for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area. (Innocenti, Manetti, Mazzuoli, Pasquare, and Villari, 1982)

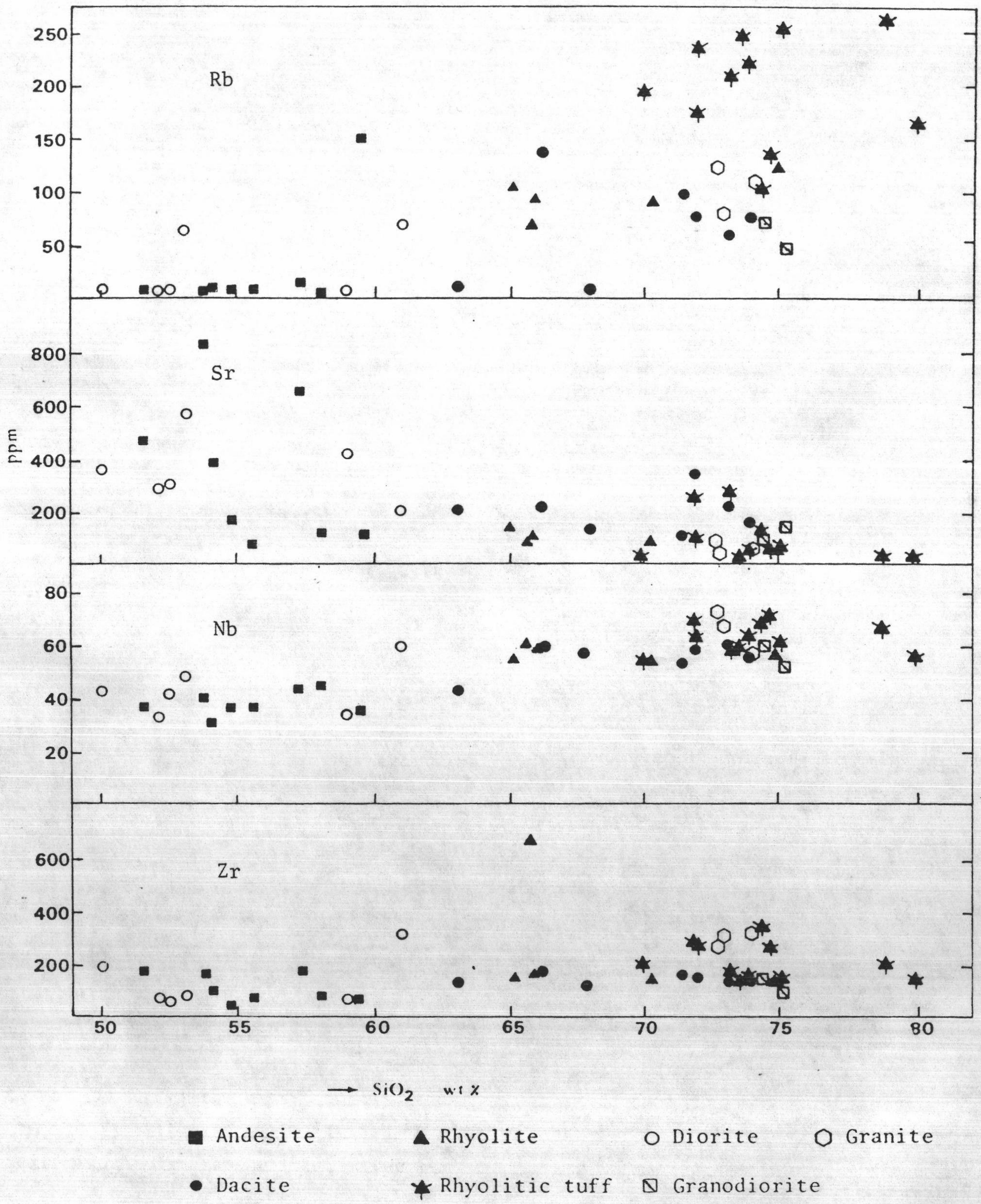

Fig. 4.11 Variation of trace elements against silica for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

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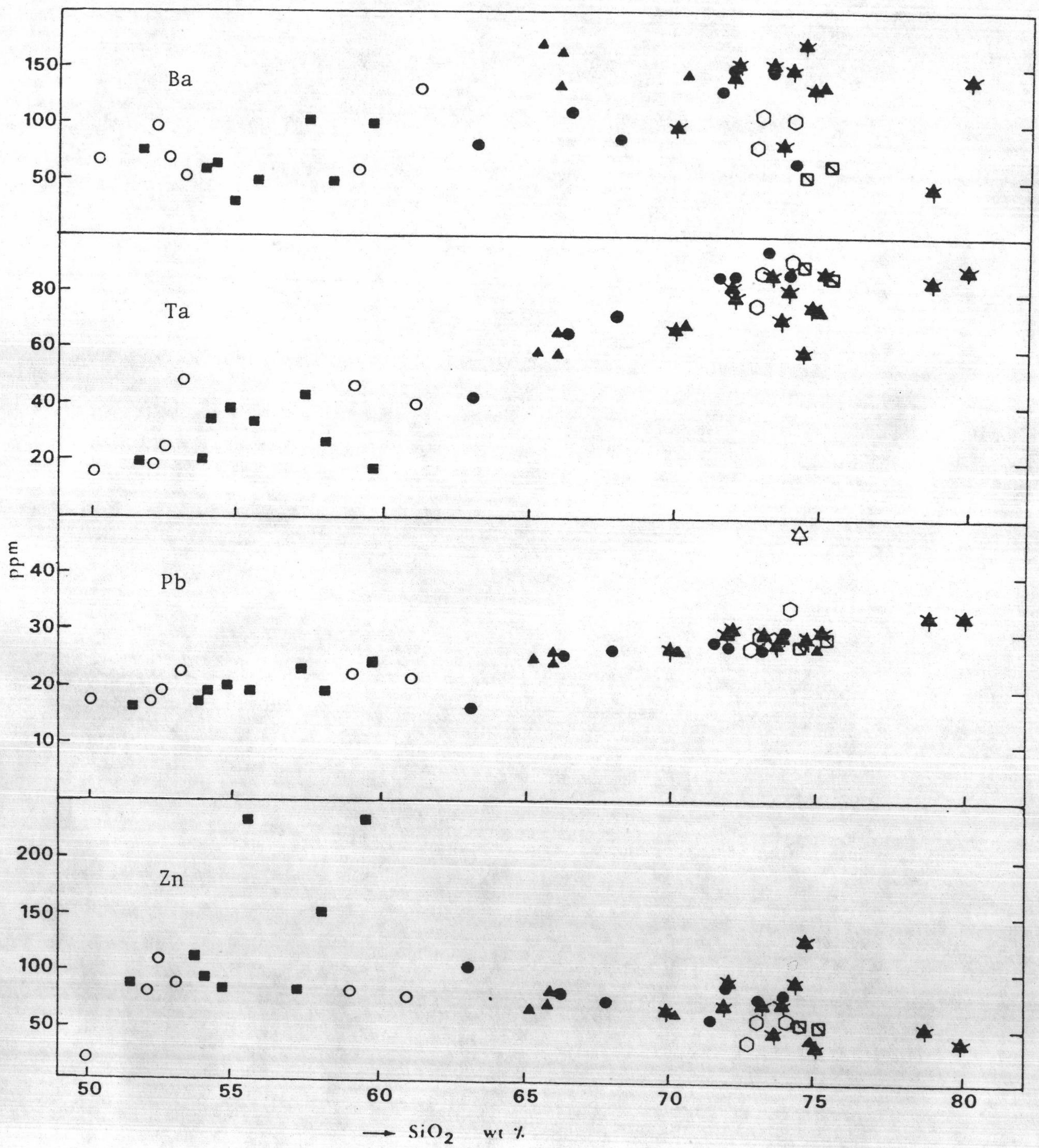

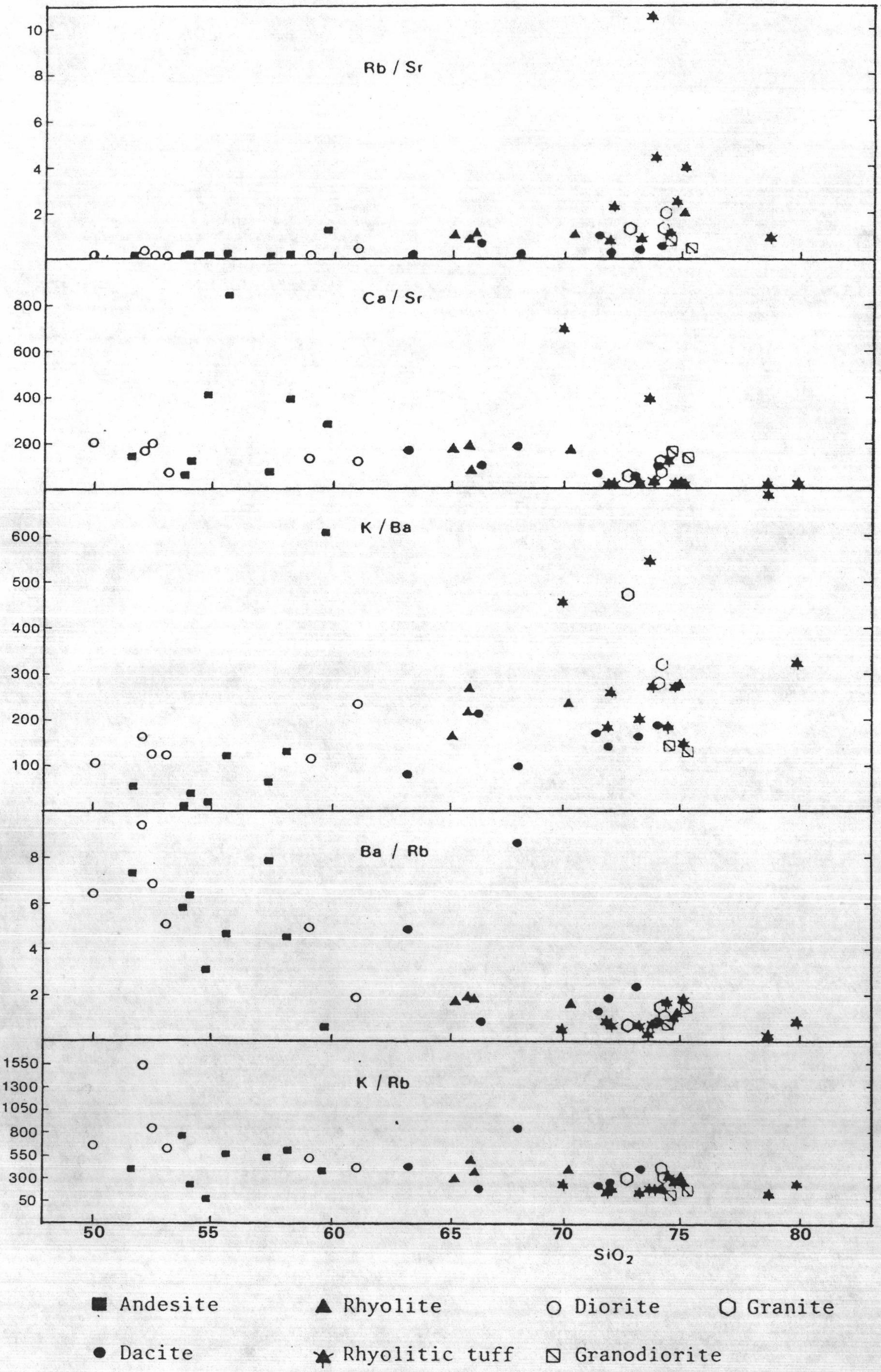

Fig.4.12 Plots of some selected trace elemental ratio against SiO_2 for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

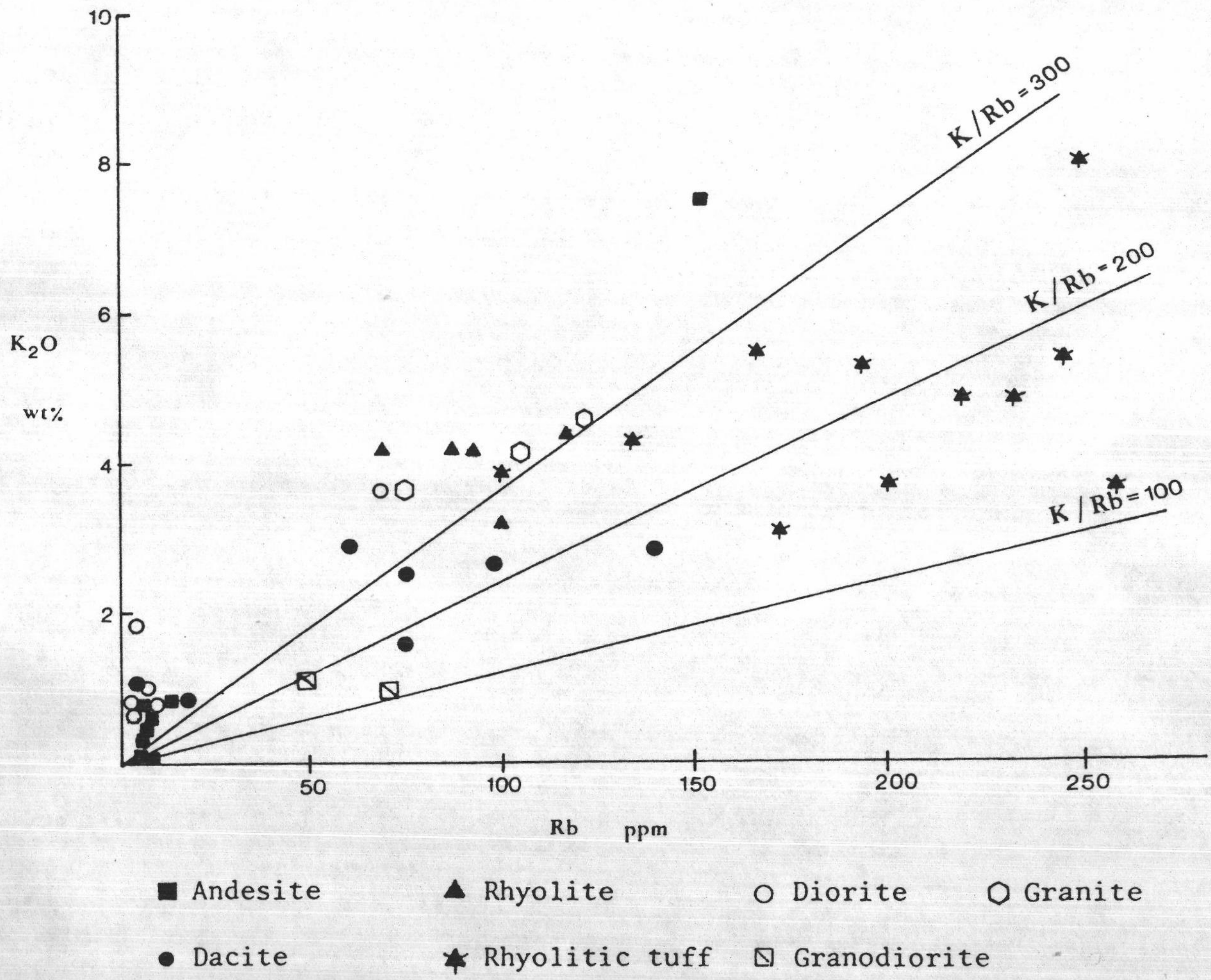

Fig.4.13 Plots of K_2O, Sr, and Ba against Rb content for the volcanic and intrusive rocks of Nakhon Sawan and U-Thai Thani area.

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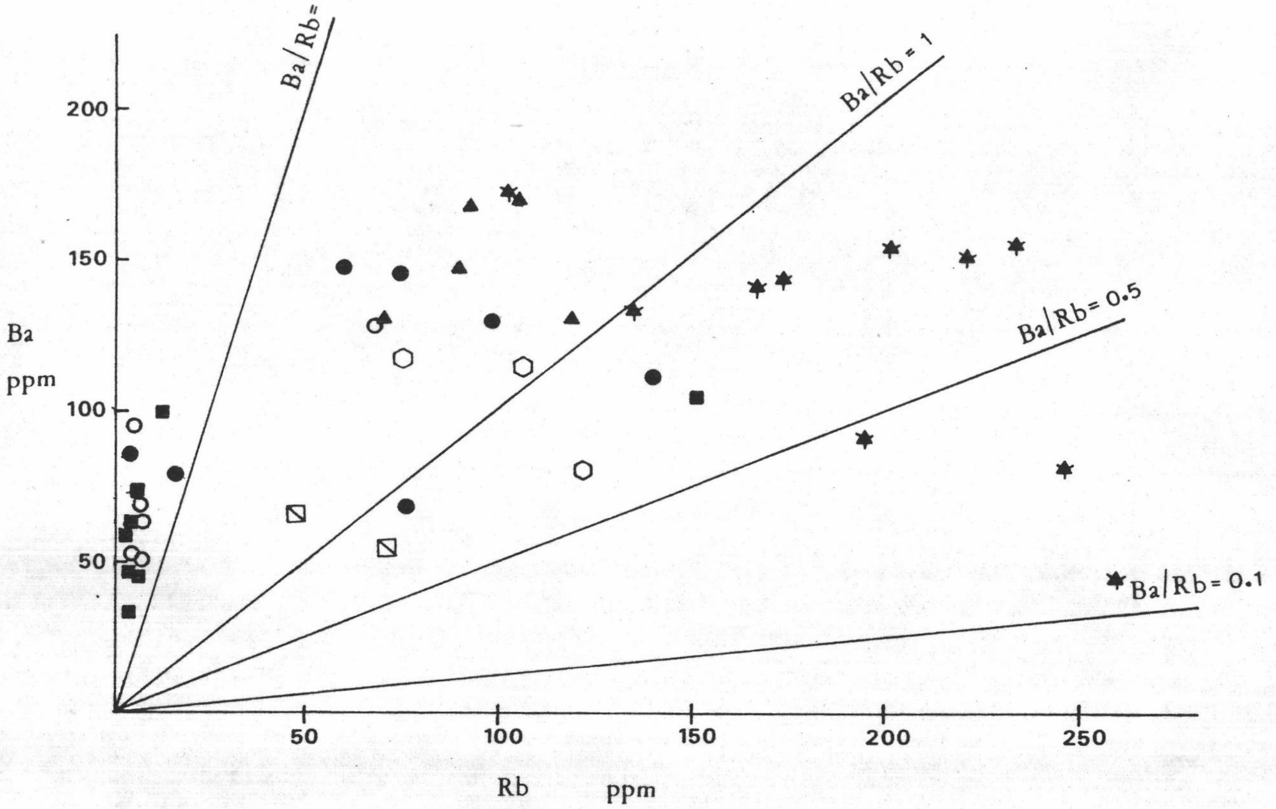

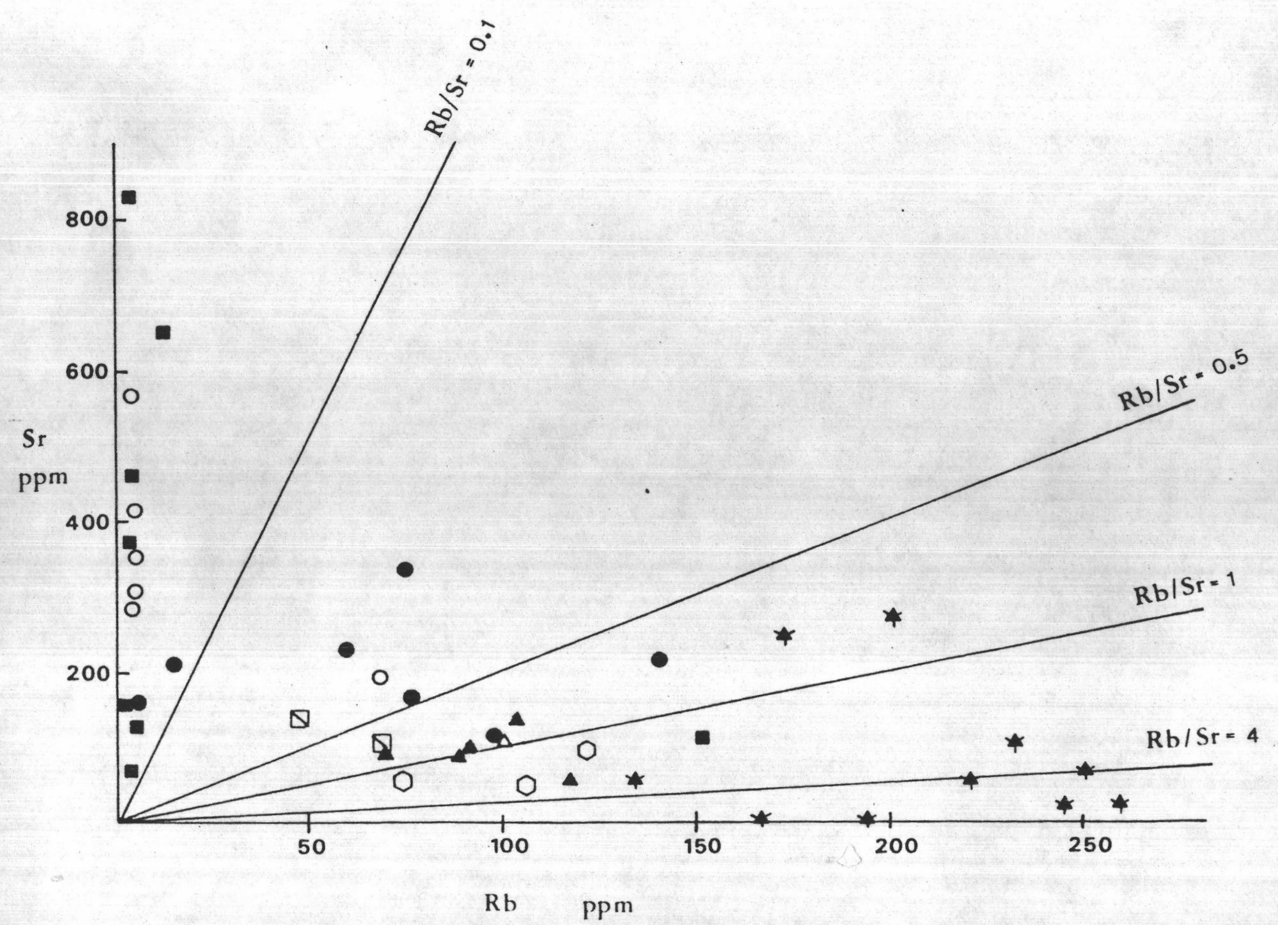

Plots of the K_2O, Sr and Ba contents against the Rb content (Figure 4.13) show that andesite and diorite have higher Ba/Rb ratio than rhyolite, dacite, granodiorite, and granite while Rb/Sr ratio of andesite and diorite are less than rhyolite, dacite, granodiorite, and granite. K/Rb ratio is not obviously higher but K/Rb contents are depleted in andesite and diorite relative to acid rocks.

From these plots, it is to note that the intermadiate rocks are relatively more depleted in Rb, K, Ba and enriched in Sr than acid rocks. It is suggesting that the acid rocks show relatively more intensive differentiation (Sheraton and Labonne, 1978).