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Petrology of the Pranburi-Hua Hin Metamorphic Complex and Geochemistry of Gneisses in it.

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Abstract: Petrographic description is given of marble, quartzite, calcsilicate quartzofeldspathite and marble, metapelite (including schist and the Hua Hin Gneiss) and other gneissic rocks, namely the Pranburi Gneiss and the Hup Kapong Gneiss, which occur in the Pranburi-Hua Hin Metamorphic Complex.

Chemical analysis of various specimens of the Hua Hin, the Pranburi, and the Hup Kapong Gneisses shows that the bulk compositions of these rocks are fairly uniform. The ratio of $Al/Na + K + \frac{1}{2}Ca$ indicates that the Pranburi Gneiss is wollastonite norm, whereas the Hua Hin and Hup Kapong Gneisses appear to be corundum norm. Moreover, major element ratios and field observations suggest that the Hua Hin and Hup Kapong Gneisses may have a sedimentary origin, whereas the Pranburi Gneiss shows igneous-like characteristics.

On the basis of mineral assemblages of metapelites, the P-T conditions of the Pranburi-Hua Hin Complex have been estimated to be at approximately 2.25–3.65 kbar and 610–680 C. However, the attempt to use mineral assemblages of calcsilicate rocks to determine the physical condition of the metamorphism is greatly affected by the degree of uncertainty in P_{H_2O}/P_{CO_2} ratio.

INTRODUCTION

A group of regional metamorphic rocks and subordinate igneous rocks outcrops in the areas of Amphoe Hua Hin and Amphoe Pranburi of Changwat Prachuab Khirikhan as an elongate belt extending approximately 50 km. from north to south (Figure 1). Most of the rocks have been subjected to high grade metamorphism and penetrative deformation. They are referred to herein as the Pranburi-Hua Hin Complex. There is still uncertainty about the age of the Complex. For instance, it was believed to be pre-Permian (Brown, et al., 1951) and also inferred to be Precambrian (Campbell, 1973; Dheeradilok, 1973; and Workman, 1975). Recently, the metamorphism of the Hup Kapong Gneiss situated north of Amphoe Hua Hin has been reported by Putthaphiban and Suensilpong (1978) using Rb-Sr techniques to have occurred 240 Ma ago. These authors have further indicated that the composition of the Hup Kapong Gneiss is identical to the Pranburi-Hua Hin Complex, and that both rocks might have originally been Lower Triassic granite which developed foliation during the Upper Tertiary deformation.

This present paper intends primarily to describe the petrology of the metamorphic Complex. In addition, this work is also aimed at investigating the geochemistry of the gneisses, establishing the physical conditions during metamorphism and elucidating the nature and origin of the gneisses.

GENERAL GEOLOGY OF THE PRANBURI-HUA HIN COMPLEX

The Pranburi-Hua Hin Complex consists mainly of gneisses, quartzites, schists, marble and calcsilicate rocks. The Complex is presumably overlain unconformably by slightly metamorphosed sedimentary rocks belonging to the Tanaosri Group (Devonian-Carboniferous) and limestone of the Ratburi Group (Permian-

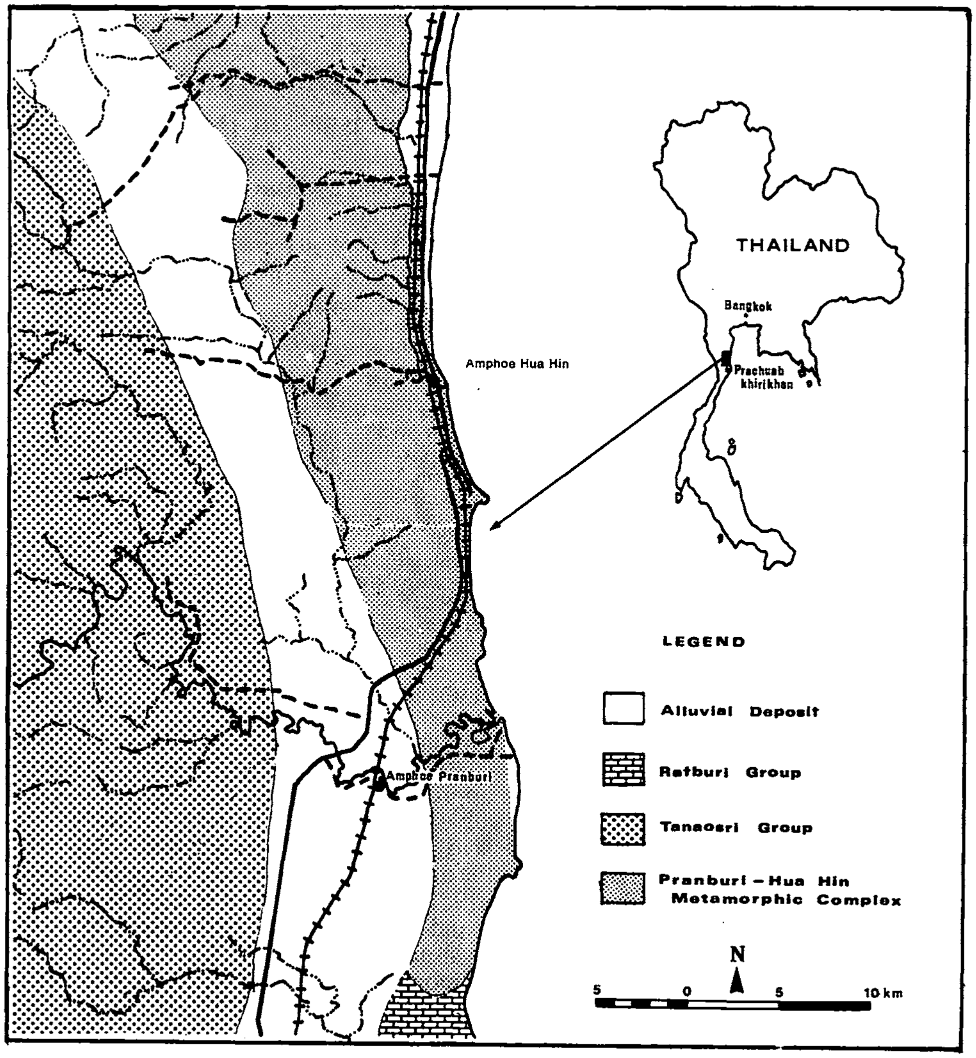

Fig. 1. Location and geology of Pranburi-Hua Hin area.

Carboniferous) in the west and the south respectively. In parts of the area the high-grade metamorphic rocks have been intruded by subvolcanic rocks, and dikes and sills of pegmatite, aplite and quartz. Furthermore, in the eastern part of the area the Complex is transected by a wide crush-zone (Figure 2).

On the basis of field investigations, the probable stratigraphic sequence of the Complex is:

marble
quartzite
calcsilicate quartzofeldspathite and marble
metapelite (mica-sillimanite schist and Hua Hin Gneiss)

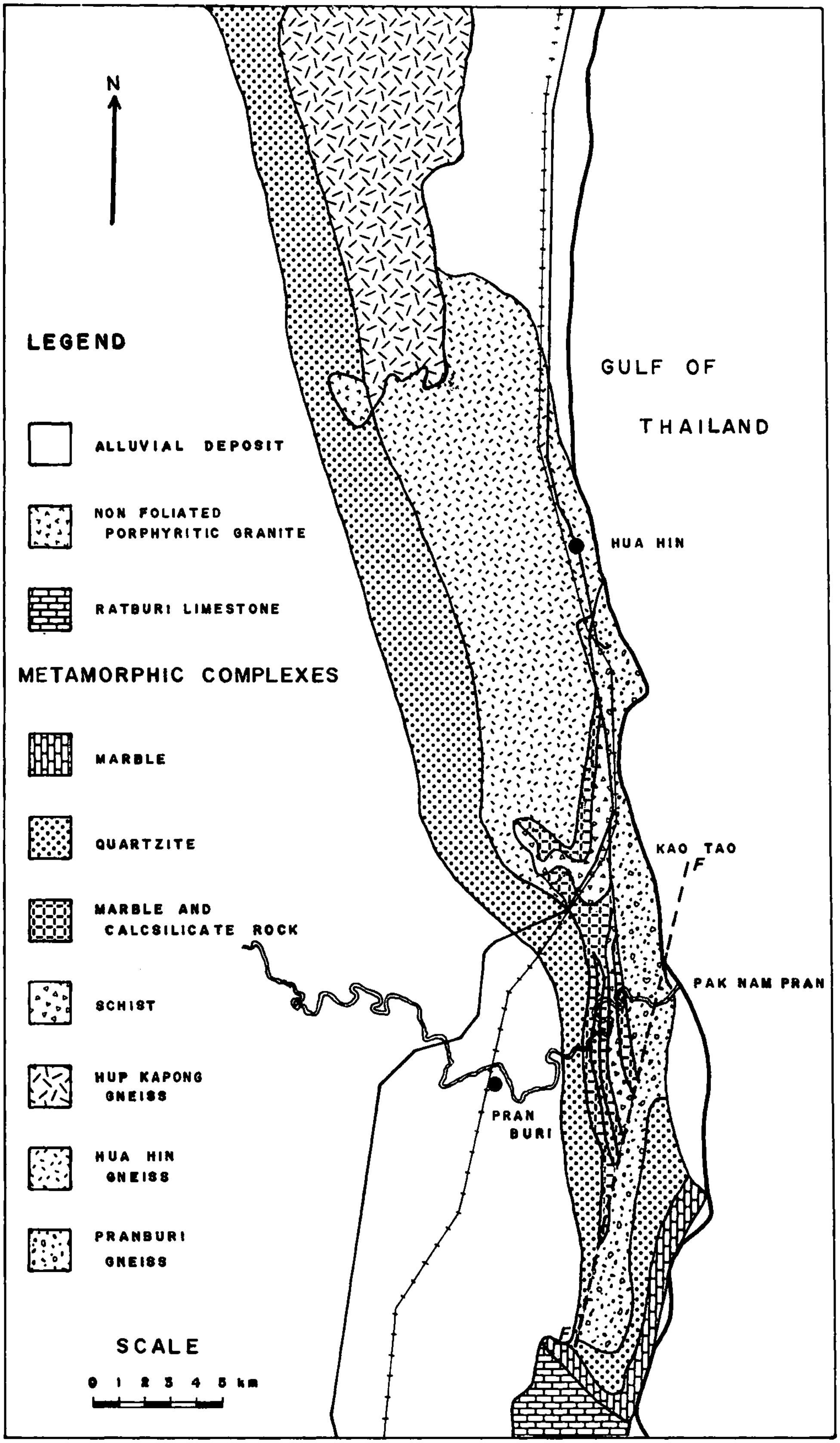

Fig. 2. Metamorphic complexes of Pranburi-Hua Hin area.

It is interesting to note that field investigations indicate that the quartzite and related rock types increase in thickness towards the north. This may be explained by either thinning out of other metasedimentary units or transformation of the former schists into a variety of gneisses. Furthermore, small bands or layers of calcsilicate rocks and schists occurring in quartzites and adjacent gneisses are common.

On the basis of differences in mineralogical composition and microstructure the gneisses can be classified into three types. The first one is referred to herein as the Hua Hin Gneiss and believed to be paragneiss. It outcrops mainly in the southern part of the Hua Hin map sheet with additional minor masses occurring in the northern part of the Pranburi map sheet. The second type is referred to as the Pranburi Gneiss, believed to have originated from the granite, and is exposed only along the east coast in the Pranburi area. Finally, the third type herein called the Hup Kapong Gneiss, was presumably derived from a younger granite. This type occurs mainly in the northern part of Hua Hin and the southern part of Tha Yang areas.

PETROGRAPHY OF ROCKS IN THE METAMORPHIC COMPLEX

Marble

Remnants of this uppermost rock unit have been, so far, found only at two localities, namely Khao Kalok and the northern part of Khao Hua Thom. The marble is relatively fine-grained, mainly light grey to white. It consists predominantly of calcite and dolomite, with minor quartz. Moreover, it is remarkable to note that numerous chert nodules ranging from a few centimetres to 35 cm. in diameter are common in certain layers within the marble.

Quartzites

Field investigations indicate that the quartzites may have been overlain by marble, even though the actual contact between the two rocks types has not been found. Microscopic studies of the quartzites show that these rocks display a variety of mineral assemblages passing from relatively pure silica quartzite into muscovite-feldspar quartzite, graphite-bearing quartzite and calcsilicate quartzite. These gradations may represent the lithological transition from originally psammitic sediments to carbonates.

The quartzites commonly range from fine to medium grain and consist of granoblastic quartz and relatively evenly arranged grains of orthoclase, muscovite, and graphite. Biotite, zircon, tourmaline and iron ore are accessory minerals. Elongate aggregates of graphite, biotite and occasionally muscovite commonly mark an impersistent foliation or lineation. Quartz may also occur in elongate grains in foliation. In places, it shows sutured grain boundaries and appears to be strained, especially where it occurs in the vicinity of the crush zone. Orthoclase may constitute up to 20 percent of the total constituents. It almost always appears to be partially or totally sericitized.

Calcsilicate minerals, for example diopside, green hornblende, grossularite, sphene, and plagioclase are invariably present in the calcsilicate quartzite. Zoisite and clinozoisite are occasionally observed, and appear to be the products of subsequent retrogression.

In a number of occurrences, layers of pelitic and quartzofeldspathic schist commonly occur within the quartzites described above. The characteristic mineral assemblages of the pelitic schist are:

quartz-biotite-muscovite
quartz-biotite-muscovite-garnet, and
quartz-biotite-muscovite-garnet-sillimanite

Plagioclase is sporadically present as a minor constituent in pelitic schists and becomes an essential mineral in the quartzofeldspathic schist which is characterized by quartz-plagioclase-biotite-garnet.

Calcsilicate quartzofeldspathite and marble

Calcsilicate quartzofeldspathite and marble are commonly layered and possess relatively medium-grained granoblastic textures. Mineralogically, the calcsilicate gradually passes into quartzofeldspathite. The layers are generally caused by alternating layers rich in diopside, plagioclase, microcline, quartz, calcite, tremolite, hornblende and sphene. Scapolite and biotite are common accessory minerals and chondrodite and periclase have been occasionally observed. The metamorphic mineral assemblages represented are:

1. diopside-plagioclase
2. diopside-calcite-plagioclase
3. diopside-calcic amphibole-plagioclase
4. diopside-calcite-calcic amphibole-plagioclase
5. diopside-scapolite-plagioclase
6. diopside-calcite-calcic amphibole-scapolite-plagioclase

Quartz and K-feldspar are common additional phases in these assemblages. The mineral assemblages (1) to (4) are the typical characteristics of the calcsilicate quartzofeldsparthite, whereas the assemblages (5) and (6) are minor and only found in a few localities.

Calcic amphiboles are of two varieties, namely, the tremolite to light-green actinolitic hornblende series, and green to greenish-brown hornblende. The latter variety is commoner than the former one. Texturally, calcic amphiboles appear to be of two generations, i.e., primary and secondary. The primary amphiboles show weak preferred orientation and may have intergrown stably with diopside, whereas the secondary amphiboles appear to be either pseudomorphs or reaction margins of diopside formed as the products of retrogressive reactions:

$$\text{diopside} + \text{plagioclase} + H_2O + CO_2 = \text{hornblende} + \text{calcite} + \text{quartz, or}$$
$$\text{diopside} + \text{plagioclase} + H_2O + CO_2 = \text{hornblende} + \text{clinozoisite} + \text{calcite} + \text{quartz}$$

Plagioclase (observed compositional range An_{35} to An_{75}) is an abundant constituent occurring in most assemblages. Potash feldspar is predominantly microcline. Myrmekitic texture is frequently observed along the grain boundaries between the two feldspars.

Periclase and chondrodite, if present, are occasionally found only in dolomitic marble occurring in the eastern portion of Khao Khuang.

Metapelites and Hua Hin Gneiss

Mica-sillimanite schist and gneiss (Hua Hin Gneiss) appear to be the lowest stratigraphic sequence in the Complex. A marked foliation and lineation is shown by the metapelites in outcrop. In thin sections, the foliation is sometimes lenticular and impersistent, being indicated by semi-parallel alignment of disseminated biotite and sillimanite, and layers of biotite-sillimanite, and quartz-feldspar (with cordierite present in some thin sections). Lineation, where present, is formed by elongate aggregates of sillimanite, biotite, quartz, and minor cordierite.

The characteristic mineral assemblages of the metapelites are:

(1) quartz-biotite-sillimanite-garnet
(2) quartz-biotite-sillimanite-garnet-orthoclase, and
(3) quartz-biotite-sillimanite-garnet-orthoclase-cordierite

These mineral assemblages accordingly represent progressively increasing grade of metamorphism. However, the mineral assemblage (2) appears to be the most abundant rock type of the metapelites belonging to the amphibolite facies. Collectively, the metapelites are relatively fine-grained, consisting of granoblastic quartz between the biotite flakes, sheaves of sillimanite, and occasionally garnet, orthoclase and minor plagioclase and cordierite.

Sillimanite occurs as aggregates of matted fibrolite, aggregates of larger rods or less commonly as coarse-grained spindles. It commonly occurs as inclusions in biotite, quartz and garnet. Garnet occurs as relatively large, dissembinated porphyroblasts commonly containing inclusions of quartz, biotite, sillimanite. Orthoclase is commonly porphyroblastic and sieved with quartz or biotite trails. It is interesting to note that the inclusion trails in the feldspar porphyroblasts seem to indicate the internal schistosity (S_i) is orientated at various angles to the external schistosity (S_e) of the rock. Plagioclase is accessory and ranges from calcic oligoclase to sodic andesine. Cordierite is confined to the high-grade metapelites. It occasionally contains tiny needles of sillimanite. Muscovite occurs as a minor constituent being foliated and non-foliated. The foliated muscovite coexists with biotite and seems to be a relict surviving from an earlier stage of metamorphism, whereas the non-foliated muscovite occurs mainly in the tensional cracks within the sillimanite rods, being a product of subsequent retrogressive reaction

The Hua Hin Gneiss occupies most of the Hua Hin area extending from the south of Khao Hok Sabu to Khao I-Run, except the central part of Khao Yai Luk Chang which is occupied by Hup Kapong Gneiss. The rock is biotite-garnet gneiss or biotite gneiss, occurring in alternate layers, which possess differences in grain size (ranging from fine to coarse) and mineral composition (Figure 3). The internal layers range in thickness from a few tens of centimetres to a few metres. It is noteworthy that the medium to coarse-grained gneiss is remarkably porphyroblastic whereas the fine-grained gneiss is commonly equigranular. In a number of occurrences, the gneiss is found interlayered with calcsilicate quartzite and schist.

Quartz, biotite, microcline, and garnet are present almost invariably. Similarly, sillimanite, orthoclase and plagioclase (An_{20} to An_{32}) are common. However, sillimanite, when present, is generally in amounts less than 1 percent of the total, and is commonly altered to muscovite. Potash feldspar is commonly porphyroblastic with varying shape (lenticular to tabular) and size. It normally shows poikiloblastic texture containing inclusions of plagioclase, biotite, and quartz.

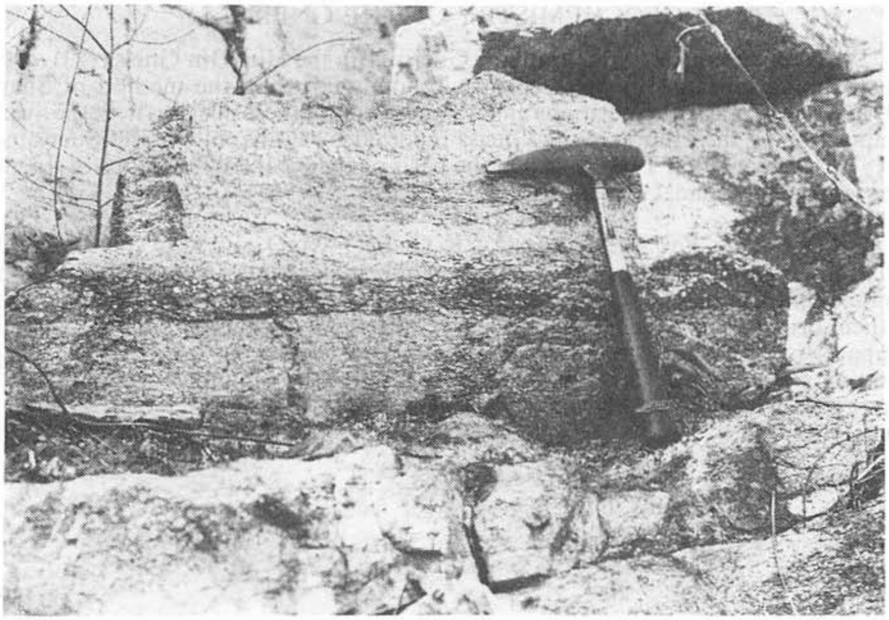

Fig. 3. Alternating layers of different grain size and composition of the Hua Hin Gneiss.

Pranburi gneiss

The Pranburi Gneiss crops out mainly along the eastern side of the southern part of the metamorphic terrain. It extends from Khao Krai Lat and Khao Sarnam Chai in the north to Khao Larn Chong Ngui and Khao Pak Dong in the south. Close inspection of the Pranburi Gneiss reveals that the rock is actually a cataclasite, ranging from ultramylonite, through mylonite to, finally, protomylonite. Dark igneous-like inclusions have been observed in many places especially those of protomylonite. Detailed descriptions have been given by Vedchakanchana et al., (1978). Quartz, microcline perthite, plagioclase (observed composition ranging from An_{23} to An_{27}) and biotite are constant minerals. Zircon and apatite are not uncommon.

Hup Kapong gneiss

The Hup Kapong Gneiss, extending from Hup Kapong towards the south at Khao Yai Luk Chang, is commonly coarse-grained, and consists of quartz, microcline perthite, plagioclase, and biotite. Apatite and zircon are ubiquitous accessory minerals. K-feldspar is remarkably porphyroblastic and commonly has a lenticular shape, but tabular shapes are not uncommon. Although the Hup Kapong Gneiss shows striking similarity in mineral compositions to the Pranburi Gneiss, some texturally and mineralogically significant differences between the two rock types are clear. Firstly, the quantity of microcline perthite in the Hup Kapong Gneiss is always much greater than that of plagioclase whereas in the Pranburi Gneiss the reverse is true. Secondly the plagioclase of the Hup Kapong Gneiss is more clacic than that of the Pranburi Gneiss. Thirdly, in places, xenoliths comprising of fragments of quartzite and calcsilicate rocks are frequently found in the Hup Kapong Gneiss, but they have not been observed in Pranburi Gneiss. The xenoliths are presumably relicts of metasediments belonging to the upper sequences of the Complex.

GEOCHEMISTRY OF THE GNEISSES

Selected specimens of the Pranburi Gneiss (16), the Hua Hin Gneiss (23) and the Hup Kapong Gneiss (10), were chemically analyzed using the method of Shapiro (1975). The chemical compositions and weight norms of these gneisses with the average composition of the Hup Kapong Gneiss reported by Puthaphiban and Suensilpong (1978) are presented in Table 1–3. On the basis of chemical compositions of the three gneisses, their chemical affinity to granite is clear.

Plots of Fe^{2+}–Fe^{2+} + Mg, $Na_2O + K_2O$–FeO–MgO, and K_2O–Na_2O–CaO on variation diagrams (Figures 4, 5, 6) show the spread of points on the diagrams. It may be noted that the chemical composition of the three gneisses seems to be inconclusive as to their origin. However, some distinctive differences are apparent when detailed comparisons are made, as shown in Table 4 and Figures 7, 8, 9. In addition, the variation diagrams of CaO, Na_2O, K_2O against SiO_2 (Figure 10) show that the Pranburi Gneiss is relatively higher in CaO and Na_2O and lower in K_2O than the others.

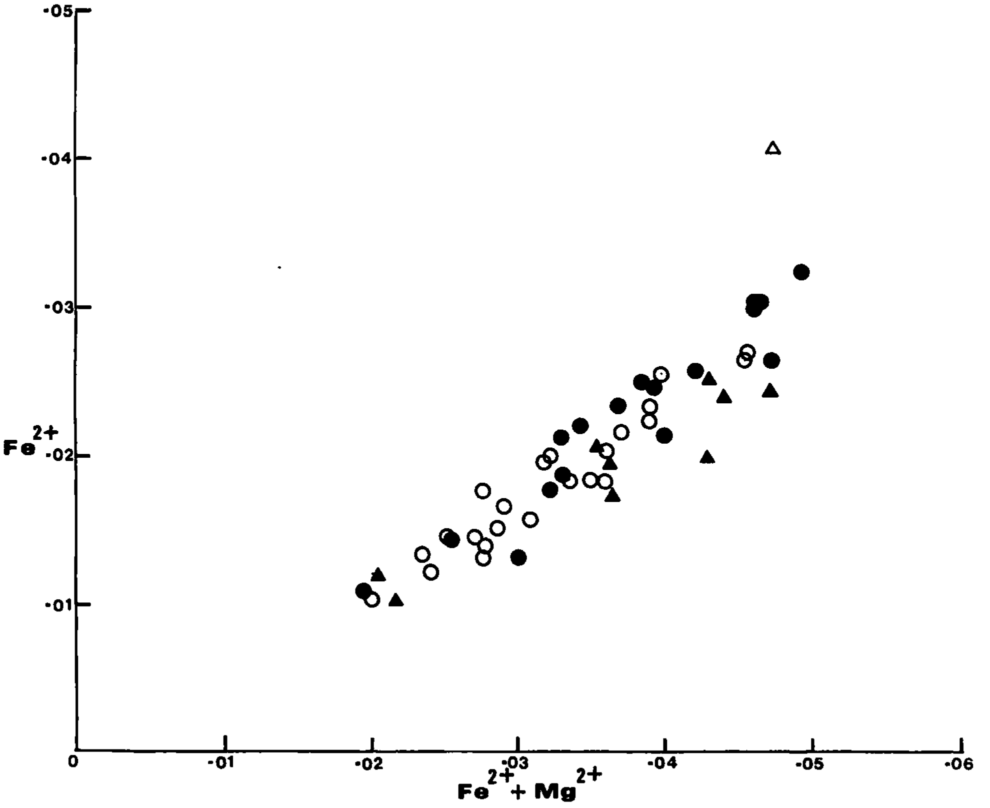

Fig. 4. Plots of Fe^{2+} vs Fe^{2+} + Mg^{2+} of the Pranburi Gneiss (●), the Hua Hin Gneiss (○), the Hup Kapong Gneiss (▲), and the average HK [△] (Putthaphiban & Suensilpong, 1978).

TABLE 1

Chemical analyses and CIPW norms of Pranburi gneiss

	PB 1	PB 2	PB 3	PB 4	PB 5	PB 6	PB 7	PB 8	PB 9	PB 10	PB 11	PB 12	PB 13	PB 14	PB 15	PB 16
SiO_2	71.96	71.00	73.10	72.89	68.38	70.05	71.50	71.50	70.58	71.25	70.65	72.72	70.58	70.07	69.96	71.76
TiO_2	.19	.25	.32	.30	.12	.34	.33	.29	.36	.36	.35	.42	.43	.35	.39	.41
Al_2O_3	12.49	13.39	13.20	14.04	13.76	13.45	13.00	12.47	13.53	13.54	13.11	13.22	13.85	13.97	13.99	14.69
Fe_2O_3	.65	1.09	1.07	.85	.96	.94	.82	1.05	1.07	1.21	1.16	1.26	.58	.97	.67	.67
FeO	.80	1.04	1.54	1.52	2.18	1.58	1.80	1.34	1.68	1.34	1.28	1.85	2.19	1.77	2.14	2.32
MnO	.03	0.06	.05	.05	.06	.07	.05	.06	.04	.06	.06	.09	.07	.07	.06	.06
MgO	.33	.44	.75	.48	.63	.49	.54	.45	.54	.58	.58	.66	.64	.59	.65	.68
CaO	3.16	3.45	1.28	1.37	3.83	3.68	3.53	3.42	3.60	3.73	3.72	2.01	4.35	3.69	4.11	2.07
Na_2O	3.33	3.56	3.41	3.27	2.92	3.50	3.24	3.28	3.69	3.52	3.71	3.41	3.71	3.63	3.14	3.59
K_2O	6.30	6.33	4.70	4.99	6.34	5.45	5.46	5.80	4.44	4.01	4.63	2.51	3.25	5.86	5.44	3.25
P_2O_5	.04	.05	.10	.12	.11	.05	.12	.05	.08	.06	.06	.07	.08	.12	.14	.13
Total	99.28	100.66	99.50	99.88	99.29	99.60	100.39	99.71	99.61	99.93	99.31	98.22	99.73	101.09	100.69	99.63
Q	24.24	21.05	30.99	30.66	19.58	22.41	25.29	24.93	25.20	28.44	24.95	37.33	27.20	19.97	22.64	31.89
Or	37.24	37.41	27.78	29.50	37.46	32.18	32.29	34.29	26.28	23.71	27.39	14.86	19.21	34.63	32.18	19.21
Ab	28.22	30.21	28.90	27.74	24.70	29.63	27.43	27.74	31.26	29.79	31.41	28.84	31.41	30.73	26.59	30.37
An	.53	1.84	5.76	6.04	5.73	4.90	4.79	2.17	7.21	9.29	5.43	9.54	11.55	4.51	7.98	9.51
C	–	–	.40	1.40	–	–	–	–	–	–	–	1.40	–	–	–	1.78
Wo	6.21	6.24	–	–	5.27	5.44	5.00	6.04	4.24	3.71	5.30	–	3.98	5.45	4.83	–
En	.82	1.09	1.87	1.19	1.57	1.22	1.35	1.12	1.35	1.45	1.45	1.65	1.60	1.47	1.62	1.70
Fs	.64	.65	1.46	1.65	3.06	1.63	2.13	1.18	1.65	.93	.86	1.74	2.89	1.93	2.79	3.09
Mt	.95	1.60	1.55	1.23	1.39	1.37	1.20	1.53	1.55	1.76	1.69	1.83	.86	1.41	.97	.97
Il	.37	.47	.61	.58	.23	.65	.62	.55	.68	.68	.67	.80	.82	.67	.74	.77
Ap	.09	.12	.22	.28	.25	.12	.28	.12	.19	.12	.12	.16	.19	.28	.31	.28

TABLE 2

Chemical analyses and CIPW norms of Hua Hin gneiss

	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6	HH 7	HH 8	HH 9	HH 10	HH 11	HH 12	HH 13
SiO_2	72.62	70.50	71.50	75.20	69.69	69.69	71.36	73.62	68.15	72.34	71.36	71.74	72.28
TiO_2	.16	.33	.22	.26	.35	.39	.37	.22	.39	.30	.23	.30	.30
Al_2O_3	15.04	15.49	15.33	12.55	15.78	15.78	15.03	13.92	15.15	15.27	15.10	15.27	14.82
Fe_2O_3	.27	.55	.46	.50	.77	1.09	1.48	.38	1.03	.76	.84	.76	.93
FeO	.75	1.85	1.27	1.44	1.33	1.69	1.61	1.05	1.90	1.33	.88	1.33	.99
MnO	.03	.07	.06	.03	.04	.02	.08	.05	.05	.02	.03	.13	.03
MgO	.39	.57	.40	.49	.61	.63	.67	.42	.77	.61	.47	.67	.56
CaO	.96	1.14	1.11	.91	1.27	1.27	1.73	1.00	1.44	1.09	1.27	1.27	1.45
Na_2O	3.07	2.94	3.03	2.69	2.44	2.89	3.23	2.77	2.72	2.29	1.89	2.60	2.30
K_2O	5.47	6.45	6.29	4.96	6.50	5.27	3.75	5.37	6.99	5.78	5.96	5.44	5.70
P_2O_5	.04	.11	.10	.12	.13	.13	.10	.14	.20	.10	.14	.10	.17
Total	98.80	100.00	99.77	99.15	98.71	98.85	99.41	98.94	98.79	99.89	98.17	99.61	99.53
Q	30.67	24.52	26.30	37.37	26.89	28.62	33.21	33.95	20.90	33.31	34.22	31.60	33.31
Or	32.62	38.13	37.19	29.34	38.41	31.17	22.16	31.73	41.31	34.18	35.24	32.18	33.68
Ab	26.01	24.91	25.65	22.76	20.66	24.49	27.32	23.44	23.02	19.40	16.00	22.03	19.46
An	4.51	4.98	4.92	3.76	5.54	5.54	7.98	4.12	5.98	4.81	5.45	5.70	6.20
C	2.34	1.84	1.73	1.38	2.70	3.28	2.73	2.04	.92	3.48	3.54	3.01	2.60
Wo	–	–	–	–	–	–	–	–	–	–	–	–	–
En	.97	1.42	.99	1.22	1.52	1.57	1.67	1.04	1.92	1.52	1.17	1.67	1.40
Fs	.87	2.52	1.69	1.81	.90	1.56	1.20	1.29	2.03	1.27	.56	1.43	.58
Mt	.39	.81	.67	.74	1.11	1.60	2.15	.56	1.51	1.11	1.23	1.11	1.34
Il	.30	.62	.42	.50	.67	.74	.70	.42	.74	.58	.44	.58	.58
Ap	.09	.25	.22	.28	.28	.28	.22	.31	.43	.22	.31	.22	.37

TABLE 2 (cont.)

Chemical analyses and CIPW norms of Hua Hin gneiss

	HH 14	HH 15	HH 16	HH 17	HH 18	HH 19	HH 20	HH 21	HH 22	HH 23
SiO_2	71.58	70.60	70.78	70.51	72.84	68.87	71.70	72.28	72.28	71.50
TiO_2	.30	.47	.26	.32	.32	.32	.29	.30	.29	.18
Al_2O_3	17.18	15.39	14.69	17.96	14.43	16.40	15.65	15.03	15.59	15.86
Fe_2O_3	1.03	.96	.60	.96	.78	.69	.86	.63	.93	.50
FeO	1.19	1.95	1.95	1.41	1.31	1.47	1.09	1.55	1.05	.97
MnO	.05	.07	.02	.04	.04	.05	.03	.04	.04	.07
MgO	.50	.75	.58	.49	.72	.62	.54	.62	.50	.40
CaO	1.27	.91	1.19	1.09	1.45	1.29	.73	1.45	1.09	.86
Na_2O	1.21	2.27	2.56	2.13	2.20	2.97	2.81	2.13	2.78	2.58
K_2O	5.87	5.44	6.88	5.36	5.19	5.90	5.36	5.27	5.61	6.31
P_2O_5	.08	.14	.05	.08	.05	.11	.11	.07	.10	.14
Total	100.26	98.94	98.56	100.36	99.33	98.69	99.17	99.37	100.26	99.37
Q	38.42	34.95	25.85	34.13	35.54	24.83	32.34	34.97	31.44	29.70
Or	34.68	32.18	40.75	31.67	30.67	34.90	31.67	31.17	33.18	37.30
Ab	10.27	19.25	21.66	18.04	18.62	25.12	23.81	18.04	23.55	21.87
An	5.79	3.67	5.56	4.90	6.87	5.73	2.95	6.97	4.81	3.42
C	6.72	4.41	.98	6.86	2.67	3.03	4.14	3.32	3.17	3.53
Wo	–	–	–	–	–	–	–	–	–	–
En	1.24	1.87	1.45	1.22	1.80	1.55	1.35	1.55	1.24	.99
Fs	.88	2.08	.83	1.31	1.27	1.66	.85	1.86	.73	1.13
Mt	1.51	1.39	.88	1.39	1.13	1.00	1.25	.93	1.34	.74
Il	.58	.90	.50	.61	.61	.61	.55	.58	.55	.35
Ap	.19	.31	.12	.19	.12	.25	.25	.16	.22	.31

TABLE 3

Chemical analyses and CIPW norms of Hup Kapong gneiss

	HK 1	HK 2	HK 3	HK 4	HK 5	HK 6	HK 7	HK 8	HK 9	HK 10	HK 11*
SiO_2	70.48	69.45	71.22	69.44	73.34	70.34	70.34	69.44	65.27	74.33	69.90
TiO_2	.37	.40	.34	.52	.21	.43	.45	.51	.74	.14	.47
Al_2O_3	15.22	15.83	15.69	16.16	15.83	16.44	15.70	15.23	16.85	14.94	14.61
Fe_2O_3	.84	1.73	1.01	1.68	.65	.90	1.10	1.46	1.23	.07	.66
FeO	1.74	1.25	1.49	1.43	.75	1.83	1.41	1.77	3.19	.87	2.92
MnO	.08	.06	.05	.04	.04	.08	.04	.03	.07	.03	.03
MgO	.80	.76	.59	.92	.45	.75	.67	.90	1.08	.34	.28
CaO	1.44	1.54	1.00	1.73	1.64	1.00	1.73	1.73	2.28	1.27	2.10
Na_2O	2.74	2.04	2.51	2.33	2.97	2.58	2.65	2.69	2.70	2.40	2.64
K_2O	5.47	6.32	5.52	4.79	4.26	4.87	5.19	5.36	5.86	4.04	4.89
P_2O_5	.08	.09	.08	.21	.09	.10	.14	.11	.22	.11	.25
Total	99.26	99.47	99.50	99.25	100.23	99.36	99.42	99.23	99.49	98.54	98.75
Q	28.64	29.08	32.04	32.79	35.59	32.87	30.25	26.76	19.50	41.37	29.74
Or	32.34	37.35	32.62	28.33	25.16	28.78	30.67	31.67	34.63	23.88	28.89
Ab	23.18	17.25	21.24	19.72	25.12	21.87	22.45	22.76	22.91	20.33	22.34
An	6.65	7.07	4.45	7.32	7.54	4.20	7.73	10.68	9.99	5.62	8.90
C	2.36	3.05	3.96	4.46	3.58	5.38	2.89	1.09	2.41	4.57	1.72
Wo	–	–	–	–	–	–	–	–	–	–	–
En	1.99	1.90	1.47	2.29	1.12	1.77	1.67	2.24	2.69	.84	.69
Fs	1.96	.25	1.38	.43	.53	1.98	.98	1.22	3.69	1.32	4.02
Mt	1.23	2.52	1.46	2.43	.95	1.32	1.60	2.13	1.78	.12	.97
Il	.70	.76	.65	.99	.39	.82	.85	.97	1.42	.28	.90
Ap	.19	.22	.19	.47	.22	.22	.31	.25	.50	.25	.56

* The average bulk composition of Hup Kapong Gneiss reported by Putthaphiban and Suensilpong (1978)

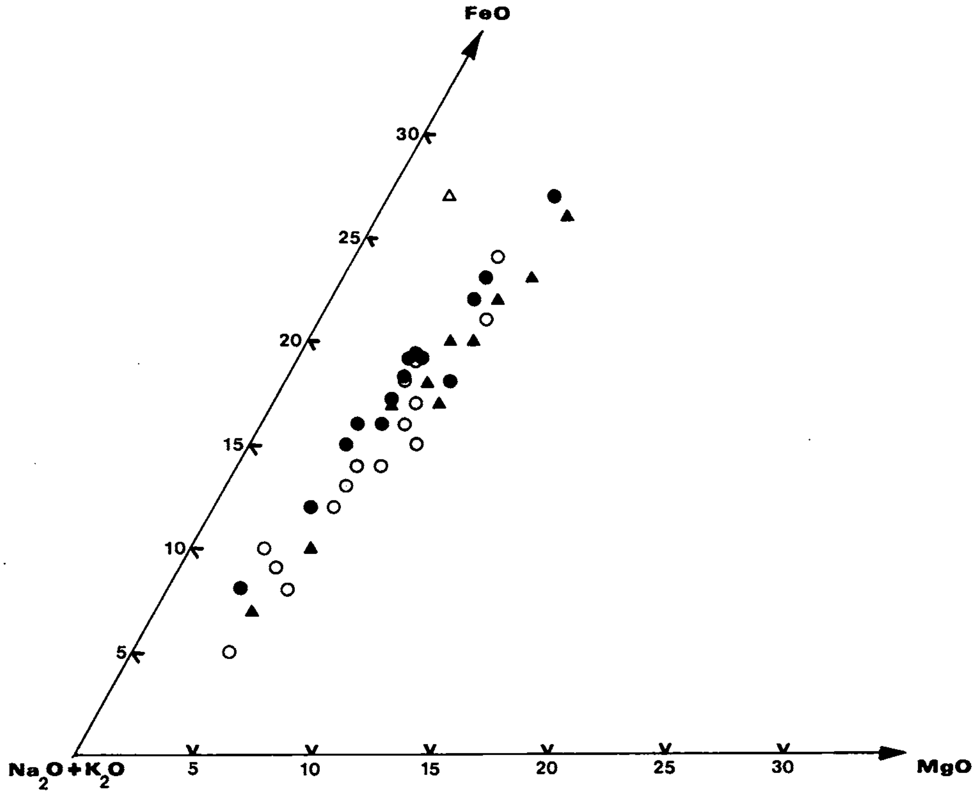

Fig. 5. $Na_2O + K_2O$–FeO–MgO variation diagram of the Pranburi Gneiss [●], the Hua Hin Gneiss [○], the Hup Kapong Gneiss [▲], and the average HK[△] (Putthaphiban & Suensilpong, 1978).

TABLE 4

	HUA HIN GNEISS	PRANBURI GNEISS	HUP KAPONG GNEISS
1.	Relatively low Na/K (< 0.857)	Relatively high Na/K (> 0.857)	Relatively low Na/K (< 0.857)
2.	Fe^{3+}/Fe^{2+} ratios average 0.27 (0.14–0.43)	Fe^{3+}/Fe^{2+} ratios average 0.28 (0.12–0.48)	Fe^{3+} Fe^{2+} ratios average 0.32 (0.04–0.63)
3.	Al/Na + K + $\frac{1}{2}$ Ca > 1.139	Al/Na + K + $\frac{1}{2}$ Ca < 1.139	Al/Na + K + $\frac{1}{2}$Ca > 1.139
4.	Corundum normative	Wollastonite normative or relatively low corundum normative	Corundum normative

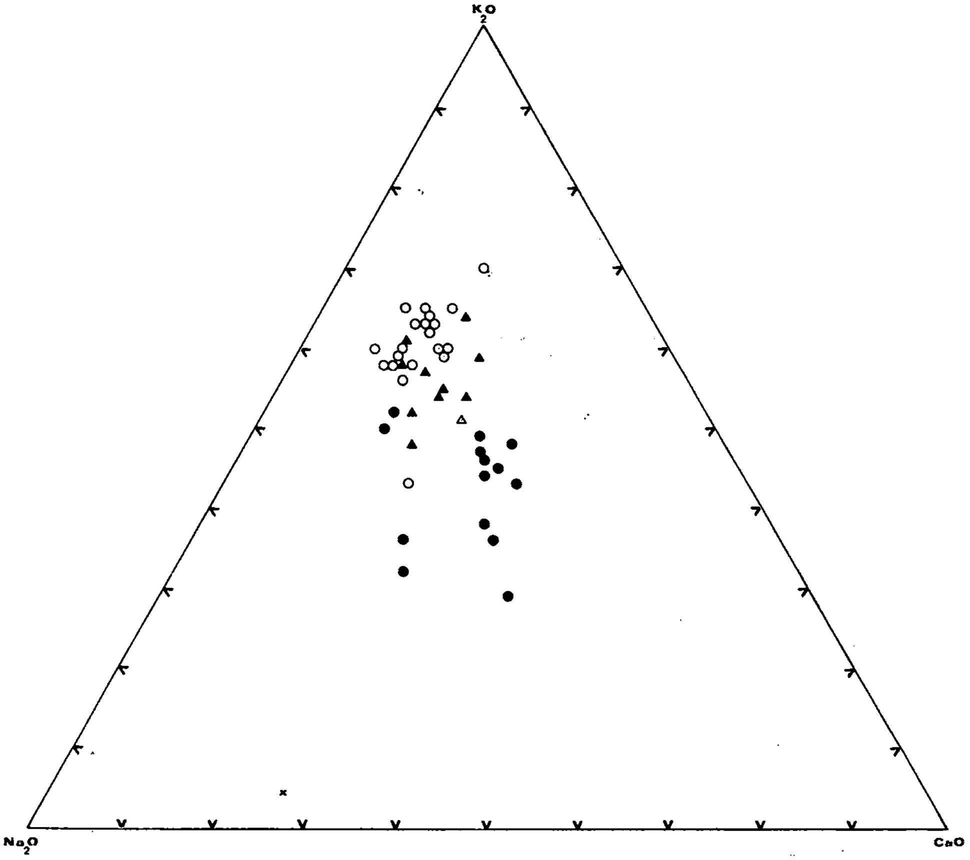

Fig. 6. K_2O–Na_2O–CaO variation diagram of the Pranburi Gneiss (●), the Hua Hin Gneiss (○), the Hup Kapong Gneiss (▲), and the average HK (△) (Putthaphiban & Suensilpong, 1978).

White et al., (1977) suggested that the I-type granites (derived from igneous sources) are generally characterized, among other things, by relatively high Na/K and Fe^{3+}/Fe^{2+} ratios, and the value of $Al/Na + K + \frac{1}{2}Ca$ being normally less than 1.1, whereas the S-type granites (originated by partial melting of sedimentary sources) are characterized by comparatively low Na/K and Fe^{3+} Fe^{2+} ratios, and the value of $Al/Na + K + \frac{1}{2}$ Ca being normally greater than 1.1. The Pranburi Gneiss has relatively high Na/K (greater than 0.857) and relatively low $Al/Na + K + \frac{1}{2}$ Ca (less than 1.139), whereas, the Hua Hin Gneiss and the Hup Kapong Gneiss have the Na/K ratios less than 0.857 and the $Al/Na + K + \frac{1}{2}$ Ca ratios greater than 1.139. Geochemically, the relative ratios of Na/K and $Al/Na + K + \frac{1}{2}$ Ca of these three gneisses seem to be in good agreement with the suggestion of White et. al., (1977) which would lead the Pranburi Gneiss to be affiliated with the I-type granite and the Hua Hin Gneiss and Hup Kapong Gneiss to be related to the S-type granite. However, Fe^{3+}/Fe^{2+} ratios of these three gneisses are close and do not follow the proposal of White et al., (1977). The similarity of Fe^{3+}/Fe^{2+} ratios and perhaps of $Fe^{2+}/Fe^{2+} + Mg$ ratios of these different gneisses might be the result of metamorphic equilibration.

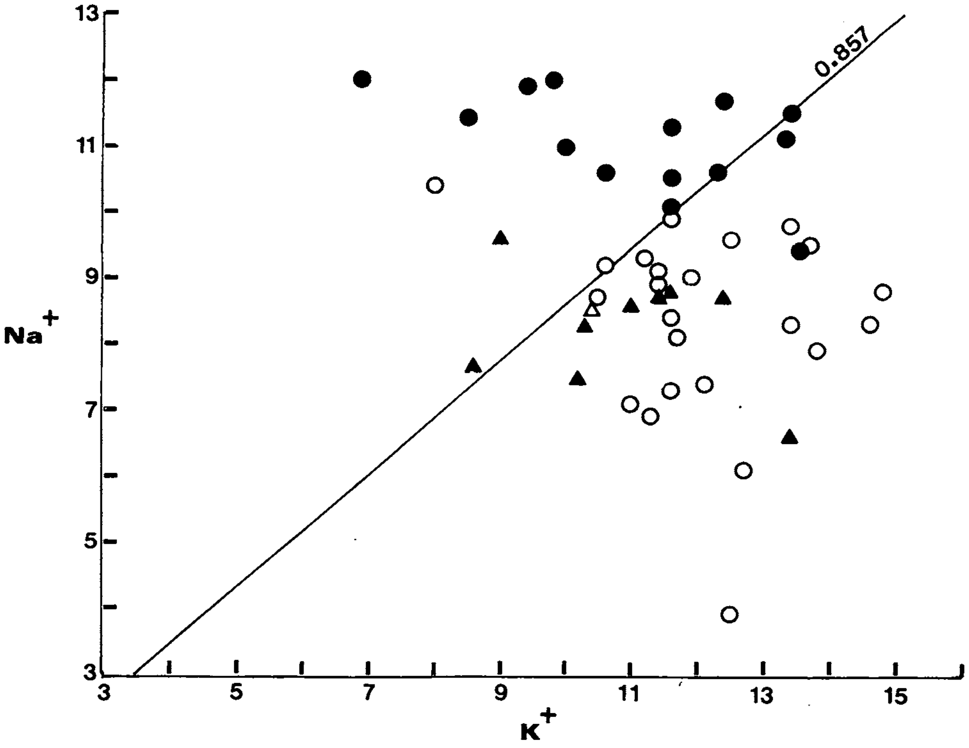

Fig. 7. Na^+/K^+ ratio of the Pranburi Gneiss [●], the Hua Hin Gneiss [○], and the Hup Kapong Gneiss [▲], and the average HK [△] (Putthaphiban & Suensilpong, 1978).

P-T CONDITIONS DURING METAMORPHISM

The metamorphic mineral assemblages belonging to the metapelites are indicative of the amphibolite facies. Furthermore, they suggest two important reactions related to an increasing grade of metamorphism:

(1) muscovite + quartz = sillimanite + K-feldspar + H_2O and
(2) biotite + sillimanite + quartz = cordierite + K-feldspar + H_2O

It is important to note that the high-grade metapelites apparently indicate virtual completion of reaction (1), with only a few rock types having reached the physical conditions characterized by reaction (2).

By assuming that $P_{H_2O} = P_{total}$, the P-T conditions of the high-grade metapelites may be depicted by the three important curves consisting of the break-down of muscovite (Kerrick, 1972), the stability relations of Al_2SiO_5 polymorphs (Holdaway, 1971) and the minimum melting of granites (Piwinskii, 1968). Accordingly, the estimation of pressure and temperature of the metapelites would probably range from 2.25–3.65 kbar and 610–680°C respectively, as illustrated by Figure 11.

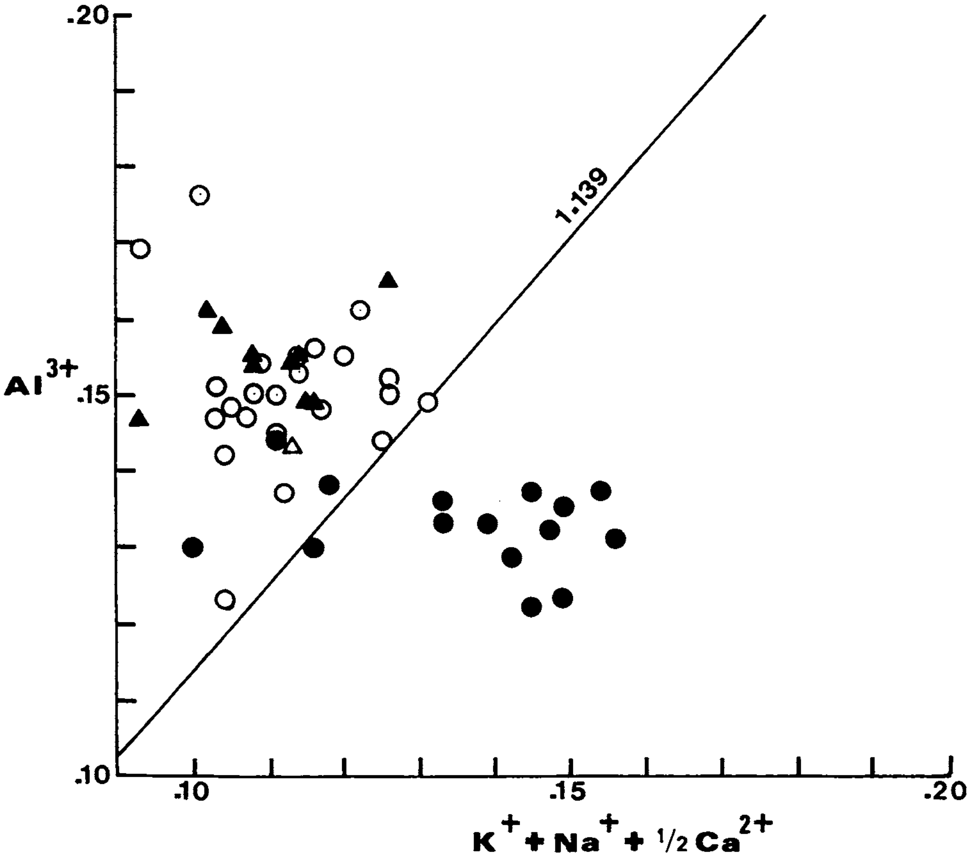

Fig. 8. $Al^{3+}/K^+ + Na^+ + \frac{1}{2}Ca^{2+}$ ratio of the Pranburi Gneiss [●], the Hua Hin Gneiss [○], and the Hup Kapong Gneiss [▲], and the average HK [△] (Putthaphiban & Suensilpong, 1978).

Moreover, the Hua Hin Gneiss, which presumably is subjected to higher grade of metamorphism than the metapelites, is cross-cut by a number of aplite, pegmatite, and quartz veins. These veins are apparently indicative of prevailing partial melting or sweat-out from the Hua Hin Gneiss under water-saturated conditions. The Hua Hin Gneiss, therefore, appears to have been subjected to a relatively higher pressure and temperature than have the high-grade schists.

DISCUSSION

The progressive regional metamorphism in the Pranburi-Hua Hin Complex, marked by changes in mineral assemblages from the schists, reflects P-T conditions in the core of the complex ranging from 2.25–3.65 kbar and 610–680 °C. The occurrence of graphite in other metasediments indicates that P_{CO_2} may have played a partial role in the metamorphic conditions, i.e., $P_{total} = P_{H_2O} + P_{CO_2}$. The reduction of P_{H_2O} would result in shifting the muscovite breakdown curve and the curve of the reaction (Bi + Sil + Q = Cd + Ksp + V) to the lower temperature position, but would move the

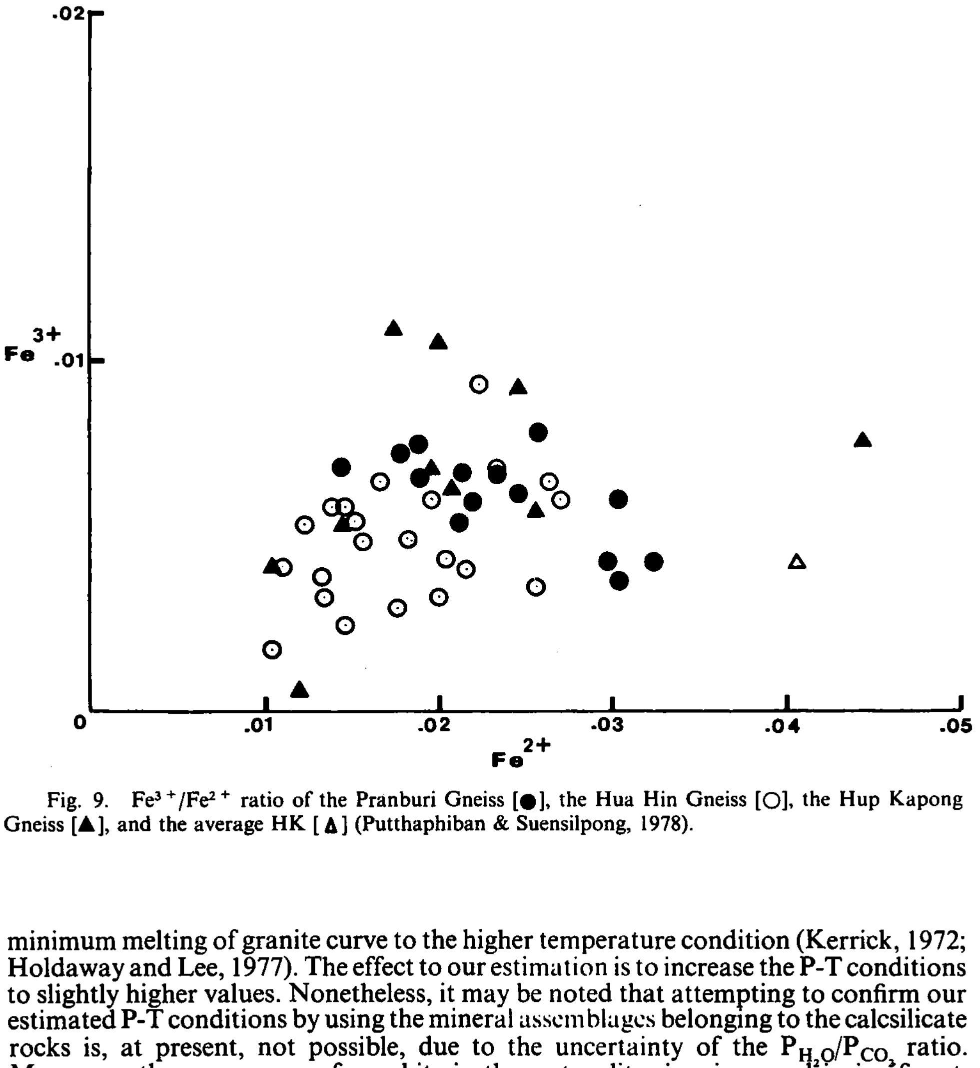

Fig. 9. Fe^{3+}/Fe^{2+} ratio of the Pranburi Gneiss [●], the Hua Hin Gneiss [○], the Hup Kapong Gneiss [▲], and the average HK [△] (Putthaphiban & Suensilpong, 1978).

minimum melting of granite curve to the higher temperature condition (Kerrick, 1972; Holdaway and Lee, 1977). The effect to our estimation is to increase the P-T conditions to slightly higher values. Nonetheless, it may be noted that attempting to confirm our estimated P-T conditions by using the mineral assemblages belonging to the calcsilicate rocks is, at present, not possible, due to the uncertainty of the P_{H_2O}/P_{CO_2} ratio. Moreover, the occurrence of graphite in the metapelites is minor and insignificant. Therefore, it is still reasonable to assume that $P_{H_2O} = P_{total}$. On the basis of recent experiments in the KNASH ($KA10_2-NaAlO_2-Al_2O_3-SiO_2-H_2O$) system with $a_{H_2O} = 1$, Thompson (1974), and Thompson and Algor (1977) indicated that the condition of the melting of albite + K-feldspar + aluminous silicates + quartz + vapour may have taken place at maximum pressure and minimum temperature of approximately 3.5 kbar and 640 °C, respectively. Since the Hua Hin Gneiss is sillimanite-bearing and believed to have been partially formed under conditions of anatexis, it is, therefore, reasonable to assume that the physical conditions during the formation of the gneiss may have been similar to those of the KNASH system determined by Thompson and Algor (1977). It is apparent that the experimental result is remarkably similar to the estimated values obtained from our studies.

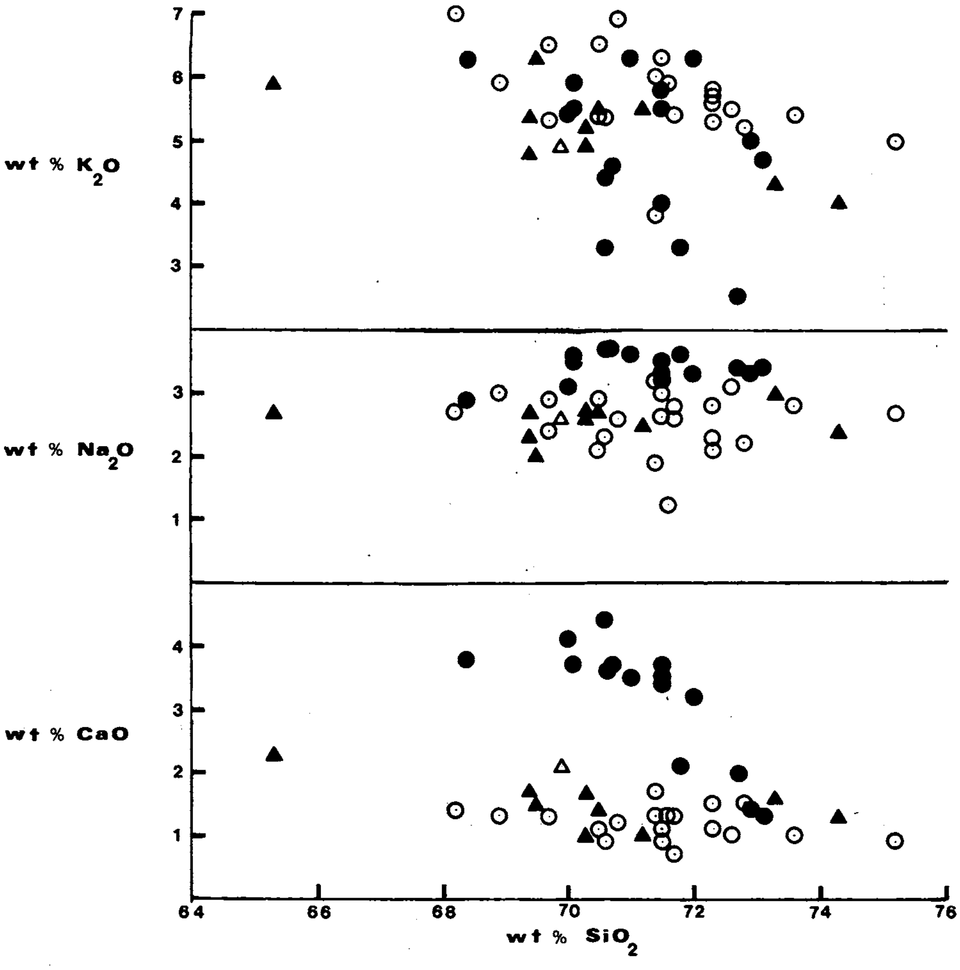

Fig. 10. Variation diagram of K_2O, Na_2O, and CaO versus SiO_2 of the Pranburi Gneiss [●], the Hua Hin Gneiss [○], and the Hup Kapong Gneiss [▲], and the average HK [△] (Putthaphiban & Suensilpong, 1978).

The original nature of the three gneisses belonging to the Pranburi-Hua Hin Complex prior to metamorphism cannot be accurately deduced, since their primary layering and microstructure have been largely obliterated and supplanted by new structures reflecting mutual crystallization of mineral grains in the solid state.

Since the Hua Hin Gneiss possesses the characteristic chemical composition of sedimentary origin (White et. al., 1977) and shows a strikingly close spatial relationship with the high-grade schists, it is reasonable to suggest that the Hua Hin Gneiss is the core of the metamorphic Complex and cogenetic with the high-grade schists.

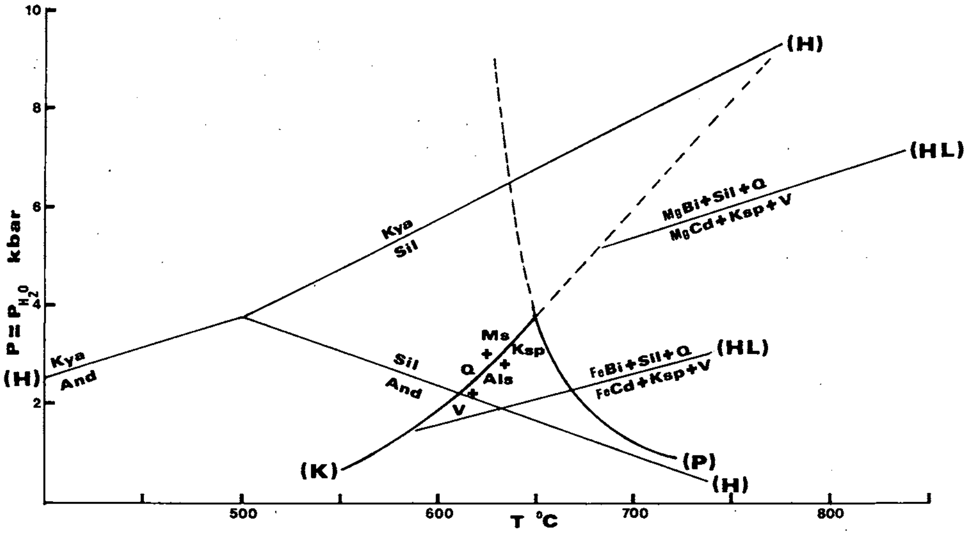

Fig. 11. Equilibrium curves used to estimate P–T conditions in Pranburi–Hua Hin metamorphic complex. (H) Al_2SiO phase relations from Holdaway (1971); (HL) Bi + Sil + Q = Cd + Ksp + V from Holdaway & Lee (1977); (K) Ms + Q = Al_2SiO + Ksp + V from Kerrick (1972); (P) the minimum melting of granites from Piwinskii (1968).

On the contrary, the Pranburi Gneiss, in close inspection, possesses the characteristics of an igneous parentage (White et. al., 1977), and shows an earlier foliation which is overprinted to varying degrees by a strong N-S foliation resulting from the Pranburi fault (Vedchakanchana, et. al., 1978). It is, therefore, unlikely that the Pranburi Gneiss is cogenetic with the other two gneisses. Furthermore, dark igneous-like inclusions have been found in several places within the Pranburi Gneiss which are in contrast to the metasediment inclusions that have been found within the Hup Kapong Gneiss. It can be suggested that the Pranburi granite gneiss may have been emplaced in the area, at least, during the early period of metamorphism.

The Hup Kapong Gneiss shows the characteristics of S-type granite (White et. al., 1977), and it has been radiometrically determined as 240 Ma old (Putthaphiban and Suensilpong, 1978). However, xenoliths consisting of quartzite and calcsilicate rock fragments have been commonly observed in the gneiss, suggesting that the Hup Kapong granite gneiss was intruded into the area probably either contemporaneously with or later than the culmination of the metamorphic episode. It may have subsequently been strongly deformed by the tectonic activities which caused shearing (Putthaphiban and Suensilpong, 1978). However, it is important to note that our field investigations show that the Pranburi fault zone does not cut across the Permocarboniferous Ratburi Limestone to the south (Figure 2). Therefore, there is no doubt that the correlation of the metamorphic and structural history with the principal recognized isotopic event, of 240 Ma ago (Putthaphiban and Suensilpong, 1978), is less clear than has been proposed.

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