CHAPTER VIII

DISCUSSION

Information on air-borne geophysical survey (Chapter III), field investigation (Chapter IV), petrography (Chapter V) and geochemistry (Chapter VI) can place a constraint on several geological topics being discussed, including geochronology, metamorphism, structural geology, origin of gneiss and granite, physical condition of granite and tectonic evolution of the Khanom and nearby areas. Discussion of individual topics are verified below.

Geochronology

The age of the Khanom Gneissic Complex is uncertain at present due to lack of cryptic geochronological data. Based on the metamorphic grade, relationship of lithofacies and tectonic evolution, it is assumed the Khanom Gneissic Complex to be Lower Paleozoic or Precambrian age, the later being more widely inferred. The Khao Pret Granite may be quite young and the Cretaceous age is proposed herein.

Many similarities exist between the Khanom Gneissic Complex and other inferred Precambrian metamorphic suites in the Shan-Thai craton. The high-grade metamorphic units constraint by geochemistry and field stratigraphic relations, can indicate their tectonic setting. The oldest rocks elsewhere in Thailand, mostly westerly overturned (Bunopas, 1981), are stratigraphically dated Precambrian gneisses, schist and calc-silicates of amphibolite facies (Pongsapich et al., 1980, 1983), with the type sections at Lan Sang National Park, Tak province, outcropping along the western belt from Chiang Mai to Kanchanaburi and Pranburi-Hua Hin (north Prachuap Kirikhan) and in the eastern Gulf coast of Thailand at Chonburi province. The Precambrian are thought to be mostly dynamothermally metamorphosed marine (flysch) sediments of a continental margin, and were deeply buried, uplifted and eroded before deposition of Middle to Upper Cambrian (Bunopas, 1992). Such metamorphic and tectonic scenario is equivalent, to some extent, to that of the Khanom rocks (see below).

Very recent data from U/Pb-, Rb/Sr- and K/Ar-determination on basement and related rocks reveal the existence of tectono-metamorphic evolution of crystalline basement of NW-Thailand (extending from Chiang Mai to Kamphaeng Phet). The Upper Triassic to Lower Jurassic time for the amphibolite- facies metamorphism can be further stressed. U/Pb data from zircon and monazite minerals from gneissic rocks give a clear evidence for the existence of a thermal/tectono-thermal event during Lower Cretaceous time and the contemporaneous intrusion of numerous granites in W-Thailand and E-Myanmar. Rb/Sr small slab investigations as well as mineral also reflect this age for a thermal overprint of at least some 600° C. Back calculation of the $^{87}Sr/^{86}Sr$ ratios for the time dependent ^{87}Rb-decay shows that the deposition ages of the paragneisses are usually less than ca. 600 Ma (Lower Paleozoic). The minimum ages for the provenances are at least 1,200 Ma deduced from the $^{207}Pb/^{206}Pb$ ages of detrital zircons. The last cooling below the 300° C isotherm during Tertiary time is reflected in numerous Rb/Sr- and K/Ar- mineral ages (Mickein et al., 1995).

Neither fossils nor dating have been reported in the Haad Nai Phlao paragneiss units (possibly the oldest unit of Khanom Gneissic Complex) and given their unsolved metamorphic and structural complexity. Earlier workers (e.g. Lumjuan, 1979; Bunopas, 1992) considered the Khanom area to be probably Precambrian. However, no evidence for a Precambrian age for the Haad Nai Phlao unit has been encountered yet in this study. Therefore, at this stage, it is strongly recommended that U/Pb dating and Ar/Ar dating techniques be applied to unravel the age of the Khanom Gneissic Complex and the subsequent thermal histories.

Metamorphism

1. Regional Metamorphism

Judging from the metamorphic mineral assemblages, it is suggested that gneiss, quartzite, schist and calc-silicate rocks of the Haad Nai Phlao Gneiss and Khao Yoi Schist belong to arenites, carbonate and pelites, respectively. The assemblage may be indicative of the amphibolite facies. Three metamorphic zones are defined herein as the biotite-garnet and sillimanite zones (Figure 8.1), where metamorphic grade increases from southwest to northeast, respectively, and is presumably restricted within the NW-trending major faults (Lumjuan, per. comm.). The metamorphic isograd is generally subparallel to foliation/schistosity.

1.1 Biotite-Muscovite+Chlorite Zone. This zone presumably represents the rather low-grade rocks of the Khanom area. It mostly occurs in the psamitic to pelitic schistose rocks as well as in the quartz-enriched rocks. The major mineral assemblage include quartz, biotite, muscovite and less dominantly chlorite as well as devoid of feldspar. Metamorphism of this isograd is observed mostly in the western part of the Khanom area.

1.2 Biotite-Garnet Zone. The medium-grade rocks of the area are represented by the biotite-garnet zone. This zone which extends from Khlong Tha Mun Si to Khlong Tha is characterized by a pelitic assemblage of chlorite, muscovite, biotite, $\pm$ garnet, quartz, plagioclase and epidote for biotite zone. This assemblage shows in the uppermost greenschist facies and may extent to the lower amphibolite facies as more calcic plagioclase is produced. Typical mineral assemblages of the garnet zone include garnet, muscovite, chlorite, biotite, quartz, and plagioclase.

The biotite-garnet zone may therefore be interpreted herein to represent a transition from upper greenschist to lower amphibolite facies.

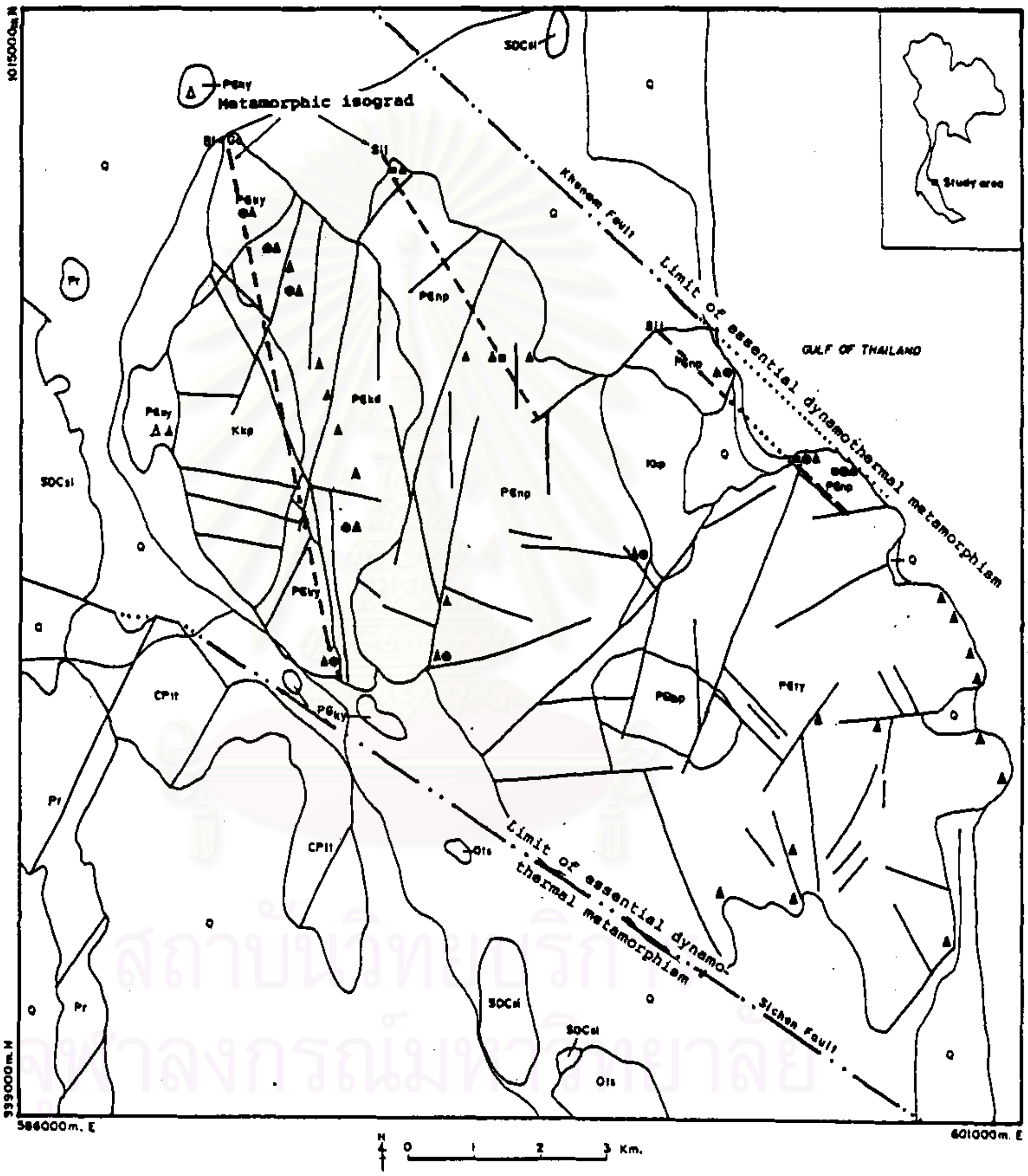

Figure 8.1. The simplified geological map of the Khanom area showing limit of essential dynamothermal metamorphism, mineral indexes , and their isograds. Sillimanite = square; garnet = circle; biotite = solid triangle; muscovite = open triangle. Major NW-trending faults are from Lumjun (per. comm.). Legend as in Figure 2.2.

1.3 Sillimanite Zone. The sillimanite zone extends from Khlong Tha Bot to Laem Nai Phlao and possibly represents the highest-grade rocks in the Khanom study area. The main rock types occurring in this zone are paragneisses. Typical mineral assemblages of this zone include sillimanite, garnet, biotite, quartz, plagioclase and muscovite.

In the sillimanite zone of the study area, pockets and veins of garnet- rich pegmatite, aplite and quartz occur very commonly. Some or all of them may be crystallization products of liquids that were formed by partial melting of the crustal or gneissic rocks in the Khanom area.

The occurrence of some index metamorphic minerals including sillimanite, garnet, biotite and chlorite is quite essential since they can unravel the metamorphic condition and tectonic activity of the area. The presence of sillimanite (in S_2 foliation) in the gneissic rocks collected from various localities in the area is an important evidence of regional metamorphic rocks. Sillimanite is regarded as a pressure-temperature dependent mineral (Winkler,1979). It never occurs with the lower pressure-temperature type of metamorphism. The petrographic investigations, both macroscopically and microscopically, reveal that the progressive (low- to) medium-grade regional metamorphism in the Khanom Gneissic Complex, is quite similar to the Barovian- type metamorphism (Winkler, 1979) marked by changes in mineral assemblages from sillimanite in the Haad Nai Phlao Gneiss, reflects pressure-temperature conditions in the core of the complex which may be depicted by the two important curves consisting of the breakdown of muscovite (Kerrich, 1972) and the minimum melt of granites (Piwinskii, 1968).

Accordingly, the estimation of pressure and temperature of the arenites would be probably 3 kbar and 650 ° C as illustrated in Figure 8.2, to garnet-bearing in the Khao Yoi Schist at the rim of the complex. On the basis of experiments in the $KAlO_2$ - $NaAlO_2$ - Al_2O_3 - SiO_2 - H_2O system (KNASH) (Thompson, 1974; 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. Since the Haad Nai Phlao 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 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. Since the Haad Nai Phlao 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).

2. Contact Metamorphism

Most of the rocks in Khanom area have been regionally subject to intermediate-grade dynamothermal metamorphism with a subsequent, mild local effect by thermal metamorphism due to injection of granitoid rocks, the latter being less common.

Contact metamorphic rock is known to differ from regionally metamorphosed rock in the physical conditions of metamorphism, i.e. only temperature without significant pressure is responsible for the contact metamorphism. Thermal metamorphic rocks generally exhibit localized recrystallization and show no preferred orientation of the mineral grains. The temperature-dependent index minerals, muscovite and tourmaline, characteristic of contact metamorphism are observed in appropriate rock compositions and at suitable temperature gradient.

The Khao Yoi Schist, which was intruded by small stock of leucocratic granite had been thermally metamorphosed and became hornfels, skarn and marble. The abundance of sulfide minerals, as pyrite in skarn rocks investigated, together with field relations, suggest that the calc-silicate rock was metasomatized by contact metamorphism as a result of the granitic intrusion. The mineral assemblage is commonly observed in the skarn rocks of the Khao Yoi Schist area include diopside, quartz, sodic plagioclase, actinolite-tremolite, calcite and epidote. This suggests that the metamorphic facies found in these rocks is hornblende-hornfels (Figure 8.3) with the maximum temperature of 550° C and pressure up to 2 kbar.

Structural Geology

In the light of structural analysis, several lines of ample evidences advocate 3 stages of deformation. The predominant regional foliation obtained from the structural analysis, which is confirmed by the field observation as well as the enhanced air-borne data, is north-northwesterly trending and steeply to moderately dipping. Two major folds are identified in the Haad Nai Phlao Gneiss and Khao Yoi Schist. Numerous mineral lineations which are consistent with minor fold axes are also observed in the field. The results obtained from the structural analysis indicate the same deformation histories for the Khanom Gneissic Complex group, though degrees of deformation are rather variable. The Haad Nai Phlao rock is strongly deformed in the center of the terrain and the deformation gradually decreases towards the southeast as the Laem Thong Yang and the west as the Khao Dat Fa rocks. This presumably suggests that the subsequent deformation formed mainly as a result of continental interaction to the east, see details in the last section. Bedding, or the original layering, is commonly recognized in the Haad Nai Phlao Gneiss and the Khao Yoi Schist and is subparallel to regional foliation.

At least three major phases which are identified from macroscopic and mesoscopic information, are also recognized by thin section petrography. S_1, which marks the first phase of deformation, is identified by well oriented mica flakes and elongate quartz, feldspar and garnet grains (see also Figure 7.8), which is generally forms a small angle (10° to 20°) to bedding. It is inferred from several evidences that

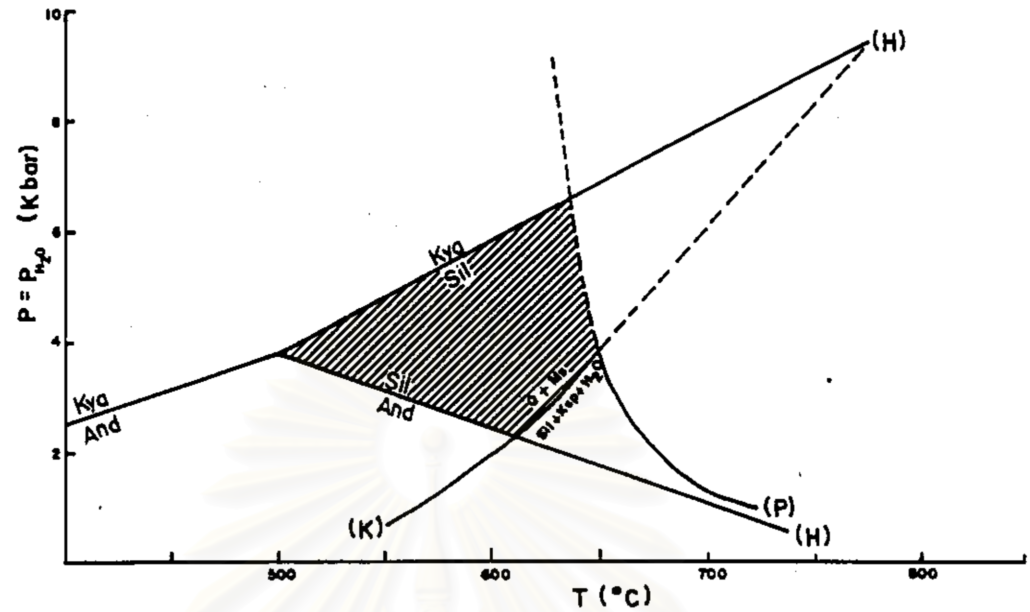

Figure 8.2. Equilibrium curves used to estimate P-T conditions in the Khamon Gneiss Complex. (H) Al_2SiO phase relation from Holdaway (1971); (K) Ms + Q = Sil + Ksp + H_2O from Kerrick (1972); (P) the minimum melting of granites from Piwinskii (1968).

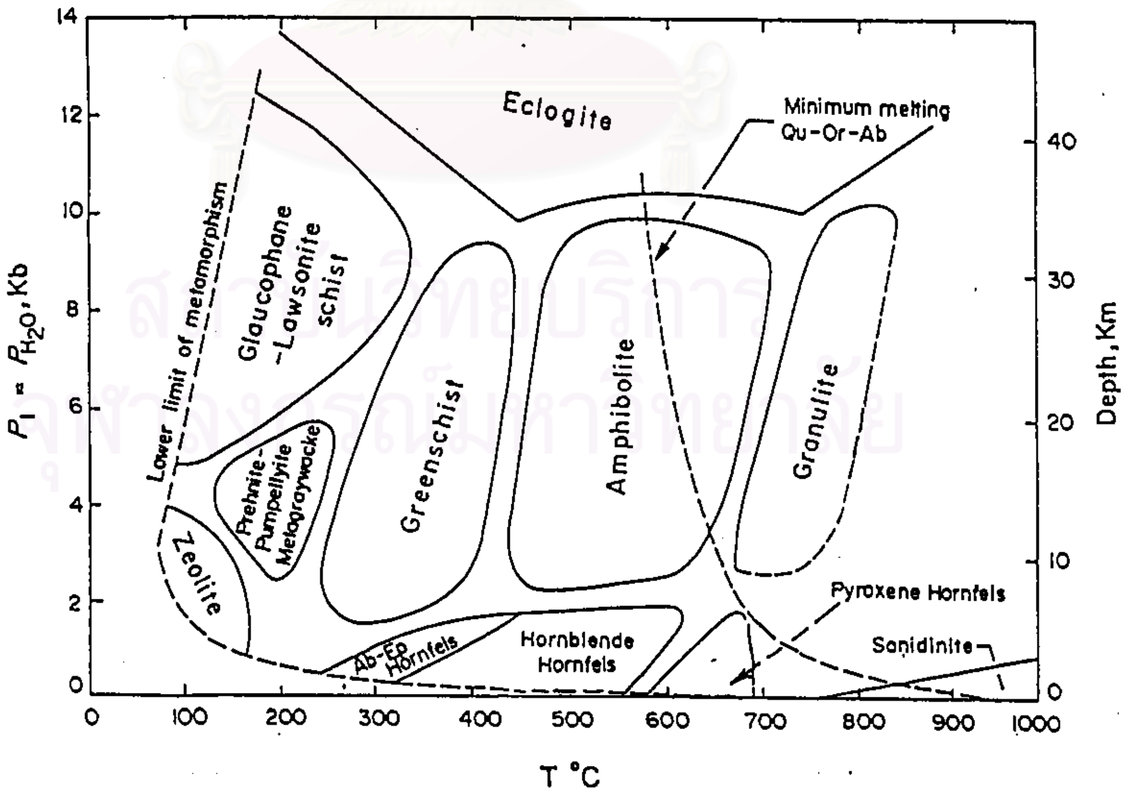

Figure 8.3. P-T conditions of various metamorphic facies (from Turner, 1968).

the S_1 foliation is, to some extent, parallel to the NW- trending major fault first recognized from air-borne geophysical information.

S_2 is identified by the development of crenulation cleavage as defined by biotite, muscovite and sillimanite (see also Figure 5.1) in the Haad Nai Phlao Gneiss and developed slip plane in the Laem Thong Yang Gneiss. The mica mineral orientation in the Khao Dat Fa Granite is ascribed to be either the effect of directed pressure which is an important physical constraint on dynamic and regional metamorphism or related only to heat effect from the nearby igneous body (western terrain Khao Pret) as so-called foliated contact metamorphism. Eventhough, the latter is quite more unlikely.

The third phase of deformation can be observed in all units which are typically offset of the conjugate fault as NNE left- and NNW-right lateral strike slip faults at the late stage of deformation.

Physical Condition of Granite

In the light of the foregoing statements of petrochemical facts and reliable topics discussed above, the physical condition of granitic rocks of the Khanom Complex can be unraveled. Winkler (1979) has shown that granitic melt can be produced by partial melting of sedimentary rocks at pressure comparable to these found in crust depths. The relatively high geothermal gradients make it likely to bring the large scale crustal reworking under relatively high water-pressure conditions with wet melting. The proportion of melt and residual solids depends upon the degree of partial melting and this is primarily dependent on the source rock composition, the temperature and the volatile content.

The Khanom Gneissic Complex exhibits a considerable range of geochemical characters and variable differentiation process during their evolutionary development. On the Shand's index plot (Figure 8.4), almost all the samples of the Khanom granites

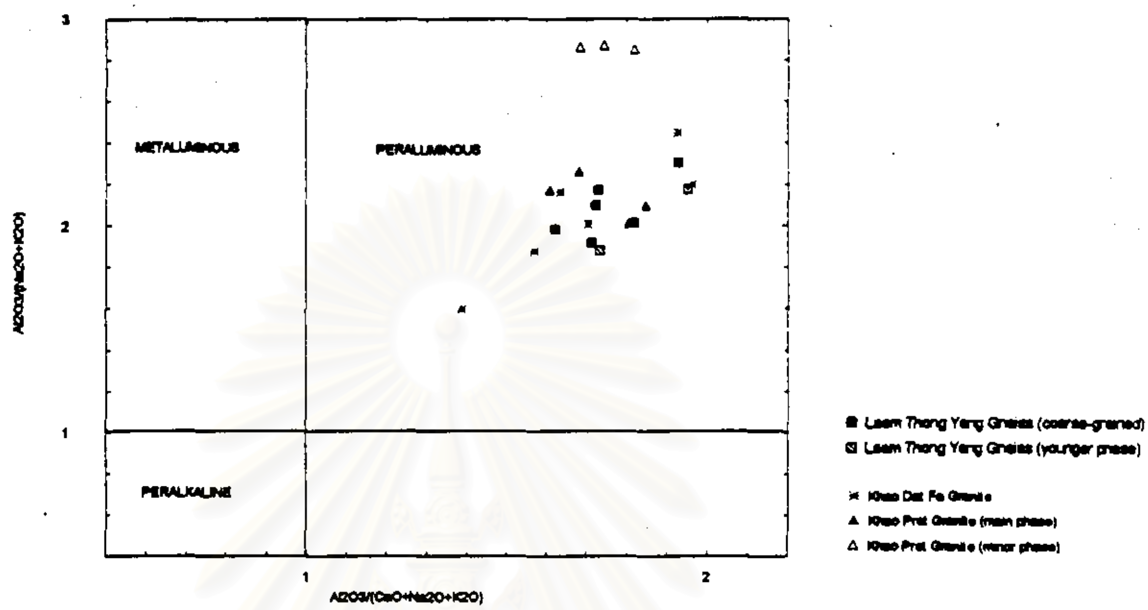

Figure 8.4. Shand's index, for Khanom granites.

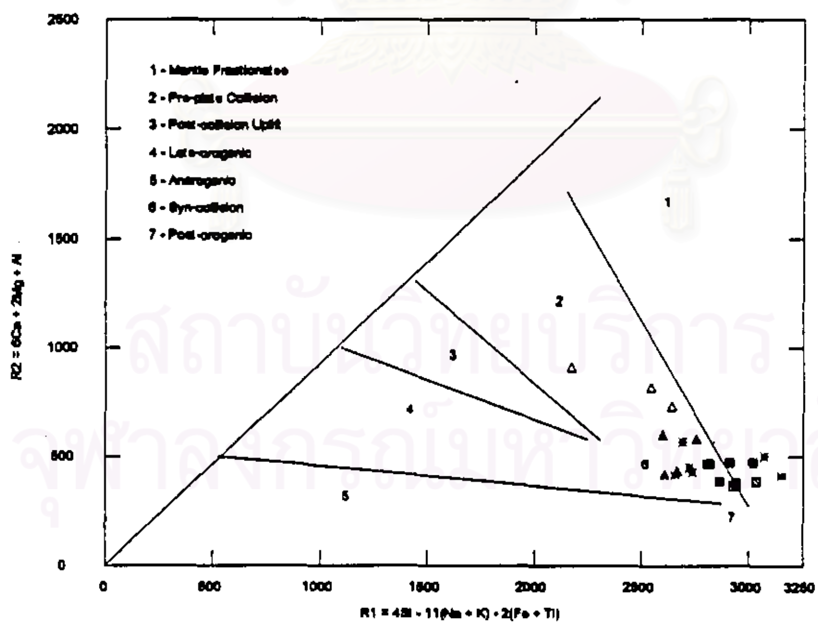

Figure 8.5. The multicationic parameters diagram for the Khanom granites (after Batcher and Bowden, 1985). Symbols same as in Figure 8.4.

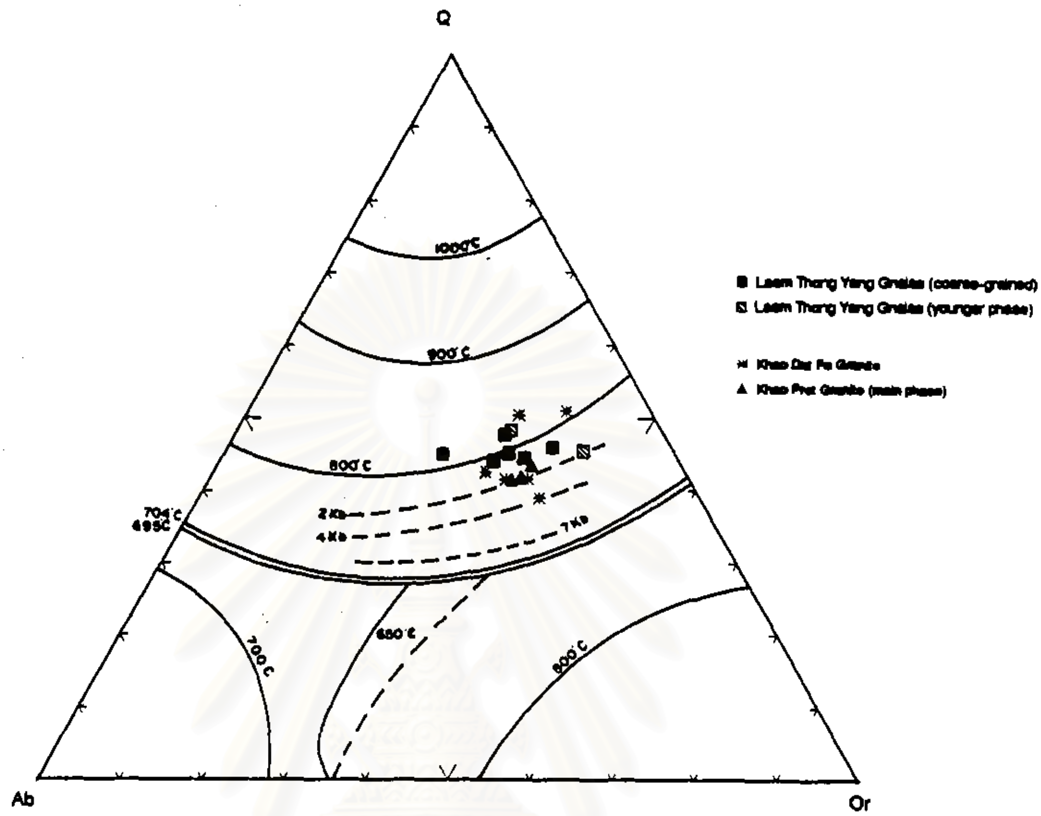

Figure 8.6. CIPW normative Q-Ab-Or diagram with various P and T after Tuttle and Bowen (1958). Q + Ab + Or > 80% are only plotted.

are peraluminous suite and are regarded herein as collision-related (Maniar and Piccoli, 1989). Figure 8.5 shows that the Khanom granites plot dominantly within the syn-collision field (crustal melts) in the multicationic diagrams designated by Batchelor and Bowden (1985).

The quartz-albite-orthoclase diagram (Figure 8.6) with various pressure and temperature (after Tuttle and Bowen, 1958) shows that the Khanom granites fall far away from the eutectic minima, signifying relatively high temperature formation of melt. The Khao Pret Granite is plotted close to the confining P_{H_2O} = 2 kbar of Q-Ab-Or ternary minima, but the Laem Thong Yang Gneiss and Khao Dat Fa Granite shows a scattered pattern which may imply that they formed at the various P-T conditions with range of P_{H_2O} = 1-3 kbar and 1 - 4 kbar, respectively. It may be explained that the former plutons represent early melts or highly fractionated melts and the latter is likely due to variable crystallization conditions.

Origin of Gneiss and Granite

The complexity of the processes involving the formation of granitic rocks in Thailand has been the subject of study by a large numbers of geoscientists through an early period in which basic disagreements existed between scientists concerning the mode of granite emplacement (Bunopas, 1981; Pongsapich et al., 1983; Charusiri, 1989). Generally, the chemical and petrological differences between granitoids may be considerable and have led White and Chappell (1983) to postulate two types of granitic rocks and two source materials such as preexisting igneous source (I-type) and metasedimentary source (originated by partial melting, S-type).

Field and petrological investigations reveal that almost all of the granitic rocks in the Khanom mapped area belong to the S- type affinity. Laem Thong Yang Gneiss contains abundantly the pelitic xenoliths and quartz lumps. Aluminum silicate minerals (as sillimanite, also may point to the sedimentary- origin. The quite abundance of garnet in the Khao Dat Fa Granite.

Generally, S-type granites have low Na/K (less than 0.857), high normative corundum (greater than 1%), low Fe_2O_3 /FeO, low CaO and high Al / 1/2Ca + Na + K (A/CNK or alumina saturation index) ratio greater than 1.139. As shown in Table 6.2, the relative ratios of Na/K and A/CNK of four granitoids are in good agreement with the suggestion of White and Chappell (1983) which would lead all units to be affiliated with markedly the S-type granite. The high contents of normative corundum in all samples (the highest in the Laem Thong Yang Gneiss) may be explained as either post-consolidation upset by percolating groundwater which dissolved the alkalies from the feldspars leaving an excess of alumina in the form of kaolinite or the more relevant, primary peraluminous nature of the plutons. Plots of variation diagrams of Na_2O, K_2O, CaO, MgO, Al_2O_3 against SiO_2 and K_2O-Na_2O-CaO (Figures 6.2 and 6.3) illustrate the spread of points on the diagrams. It may be noted that the chemical composition of the three granites seems to be inconclusive as to their origin. The Khao Pret Granite is relatively higher in CaO, MgO and lower in K_2O than the others and its samples also define near-linear arrays on fairly systematic variations with increasing SiO_2. The ternary Na_2O+K_2O-FeO*-MgO diagram (Figure 6.4) after Irvine and Baragar (1971) can be used to distinguish tholeiitic from calc-alkaline rocks. The total samples are plotted in the calc-alkaline field. These granites are peraluminous, since Al_2O_3 / Na_2O + K_2O + CaO ratio is higher than 1, following the Chappel and White (1974) 's classification. The difference of trace elements contents in the gneissic complex rocks are possibly due to different degrees of partial melting.

The REE patterns in the Khao Pret Granite, Khao Dat Fa Granite, Laem Thong Yang Gneiss and Haad Nai Phlao Gneiss show strongly fractionated REE patterns with LREE/HREE ratio((La/Lu)cn) with an average 111.61 ($\pm$23.36), 87.57 ($\pm$17.67), 62.40 ($\pm$19.64) and 54.28 ($\pm$2.07), respectively. In particular, its high LREE/HREE ratio suggests that all granitoid suites contains a substantial proportion of material derived from the reworking of sialic crust (Hong, 1992). The high fractionated REE patterns, the mild Eu negative anomalies and the wide range of Sr content in the samples postulate a high degree of partial melting involving plagioclase. Both zircon and garnet, which have high heavy REE contents, may be left in the

Note : FeO* = FeO + Fe_2O_3 x 0.89981

residual melt, and the plagioclase crystals melted to form a granitic magma during the process of partial melting (Hong, 1985). The Khanom granitic rocks contain negative Eu anomalies, large REE content (range total REE 60-49.9 ppm) and LREE / HREE (range (La/Lu)cn = 8.9 - 66). Based upon these REE data, it is possible that the Khanom samples are from continental or continent margin setting (Cullers and Graf, 1984).

Two problems of granite genesis must be addressed. The first is the formation of granitic magma itself, and the second is the cause of variation within suites. Primary granite magmas have two possible modes of origin. They may be generated by differentiation from another pre-existing magma type or they may be partial melts from particular source rocks. Differentiation by fractional crystallization is the evolution of single magma type into batches with different chemical compositions. Linear trends on Harker diagrams can be explained by the crystal fractionation or removal of the early crystalline phases from the melt which is gradually depleted in the elements involved. Theoretically, the most mafic granite is the oldest phase and the most felsic granite is the younger one. In the the Khanom granite terrain, this is not the case. There are many separate suites, each of which must have their own parents.

Tectonic Evolution

When taking into account the field synthesis together with the detailed air-borne geophysical information and petrochemical investigation, tectonic evolution of the Khanom Gneissic Complex and its related rocks is visualized. As shown in Figure 8.8, the complex is presently located in the eastern part of Shan-Thai microcontinent. The occurrence of inferred Precambrian gneiss, schist, quartzite, and calc-silicate rock in the study area may lead to the deposition of siliciclastic to pelitic and carbonate sediments (Khao Yoi Schist and Haad Nai Phlao Gneiss) as part of passive continental margin of the Gondwana megalandmass. Though unclear, intrusion of granite (Laem Thong Yang Gneiss) may have happened subsequently. These sediments and injected granitoids may have been subject to regional metamorphism up to the lower amphibolite facies possibly within the Precambrian Period. This resulted in the arrangement of feldspar and mafic minerals which are marked as the development of N-S S_1 foliation of the rocks. Subsequently, during the Ordovician, the marine deposition of intertidal to subtidal carbonates (Thong Song Limestone) occurred (see Wongwanich, 1990; Srisakulrat, 1995) in western and central portions of the studied area. Following was the deposition of thick, deep-marine clastic sediments of Middle to Upper Paleozoic (Khao Si In and Lam Thap Formations), all of which may have taken place in the sedimentary wedges of passive continental margin onto the Shan-Thai (-Malay) craton, where source region was from the terrigineous nearby exposed Shan-Thai Landmass. Elsewhere the major break existed immediately after the separation of Shan-Thai (-Malay) from Gondwana during Late Paleozoic based upon paleomagnetic study (Bunopas, 1981) and the deposition of carbonate shelf facies onto the underlying sedimentary wedge sequences during Permian (Ratburi Limestone) have occurred.

Later on possibly during Triassic Period, Shan-Thai (-Malay) cratonic block became collided with the Indochina block. Henceforward, with the accumulated stress and heat, partial melting of the amalgamated lithospheric crust may have happened and resulted in the generation of S-type granitoid rocks (Khao Dat Fa Granite). Strong S_2 foliation and fold axis in gneissic rocks may have developed in the NW-NNW direction in response to the triggering compressive stress event (see also Figure 8.8). The continent-continent collision may have continued until the granite became slightly foliated and the regional metamorphism may have reached the amphibolite facies as supported by the occurrence of sillimanite $\pm$ garnet. The conjugate NNE fault may have formed at this stage. Partial melting of the crust may have existed and the younger S-type granitoid suite (Khao Luang Granite and Leucocratic Granite suites) may have formed possibly postdating the Khao Dat Fa Granite. Therefore, no prominent (secondary) foliation was encountered in the Khao Luang Granite. In addition, several Sn-W deposits were also reported in the south immediately outside the study area (Charusiri, 1989), suggesting the concurrence of S-type granite. However, during Cretaceous Western Burma block (+ Phuket microcontinent) may

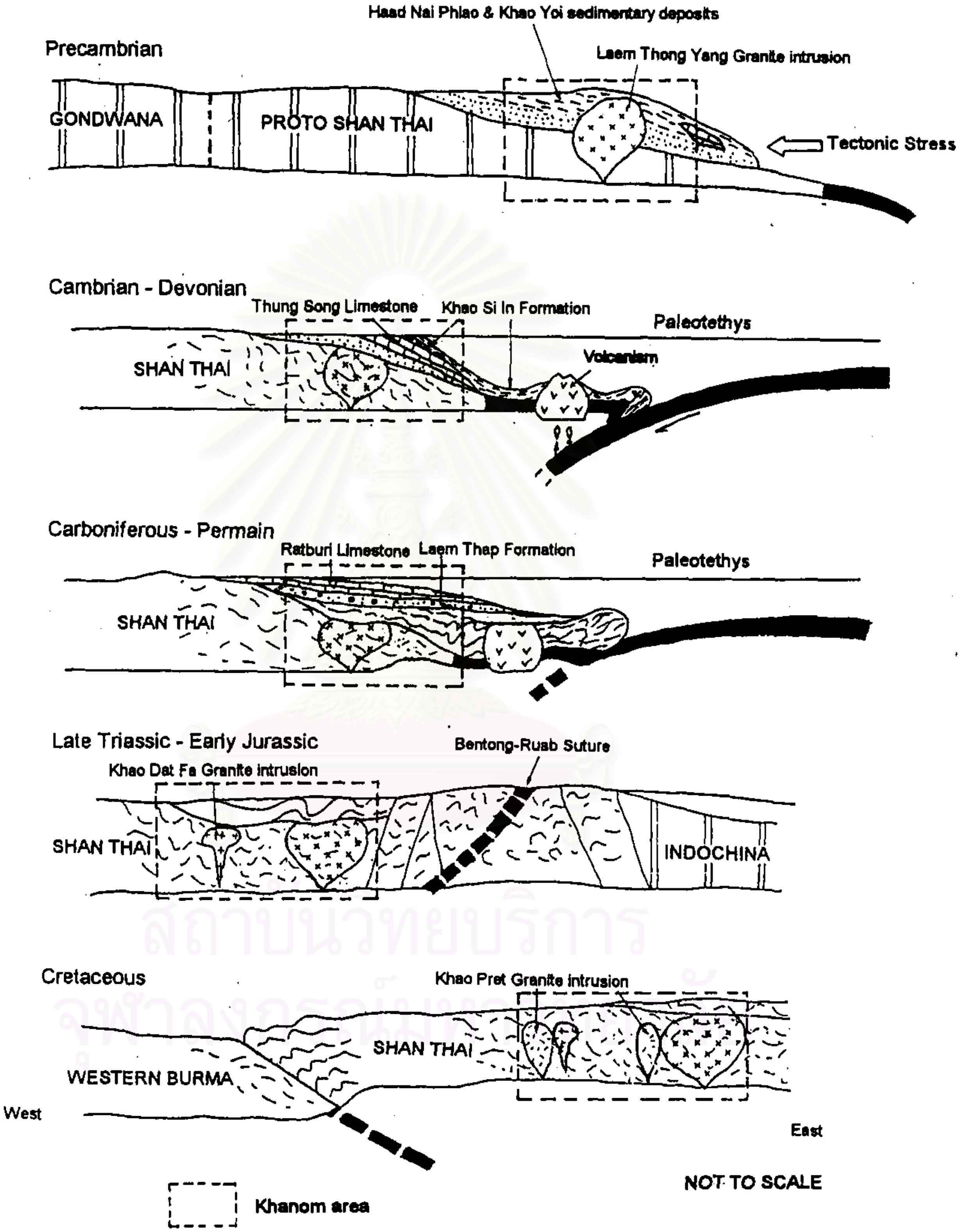

Figure 8.7. A plate tectonic reconstruction showing the tectonic evolution of the Khanom area since Precambrian.

have collided with the Shan-Thai (-Malay) block, and as a result partial melting of the crustal rock existed and the generation of S-type Khao Pret Granite developed. Perhaps the abutment of Western Burma block with Shan-Thai (-Malay) may have intended enough to produce the major fault displacement in the area since the compression of Western Burma into Shan-Thai (-Malay) existed in the more- or less-N-S direction, then the faults (and related tectonic structures) developed in NE direction with the sinistral movement and NW- conjugate sets in the study area. This situation is quite similar to the tectonic model proposed earlier by Polachan and Sattayarak (1989) for the development of the pull-apart basin in the Gulf of Thailand. Presumably this event may have most intended during Tertiary period, which may have given rise to the prominent NE- trending fault with the minor E- trending joint and fault sets.