CHAPTER VII

STRUCTURAL GEOLOGY

Regional Structure

Regional tectonic events of southern peninsular Thailand (Figure 7.1) are oriented in the N-S direction and include rocks ranging in age from Lower Paleozoic to Quaternary. The granitic batholiths along the eastern half of the peninsula are mainly Triassic to Jurassic whereas those along the western coast are mainly Cretaceous to Tertiary (Charusiri, 1989). The major structural feature includes folds and faults which share more or less similar attitude (north-south). The antiforms tend to be restricted to sediments peripheral to the granite plutons and may possibly be the result of granite emplacement.

The development of the N-trending Tertiary basins in the Gulf of Thailand is attributed to the northwards progressive collision of the Indian Craton with Eurasia since 40-50 Ma. Penetration of India into Asia caused clockwise rotation of SE Asia, resulting in increasingly oblique subduction of the Indian Ocean Plate beneath the western edge of SE Asia (Charusiri, 1989). This leads to movements along the strike-slip faults with the associated development of pull-apart basins in this region. The Three Pagodas and Ranong-Khlong Marui fault zones are inferred to have been active since Oligocene time. The actual fault trend and distribution can be related to the strain ellipsoid during dextral simple shear with N-S compression. According to the dextral shear model, the NW-SE Three-Pagodas fault zone is the principal right-lateral strike-slip fault, whereas the NNE-SSW Ranong-Khlong Marui fault zones (Figure 7.1) are conjugate left-lateral strike-slip faults (Polachan and Sattayarak, 1989). The left-lateral movement on the Three Pagodas Fault as shown by Bunopas (1981) were possibly caused by the E-W compression (present position) between the Shan-Thai and

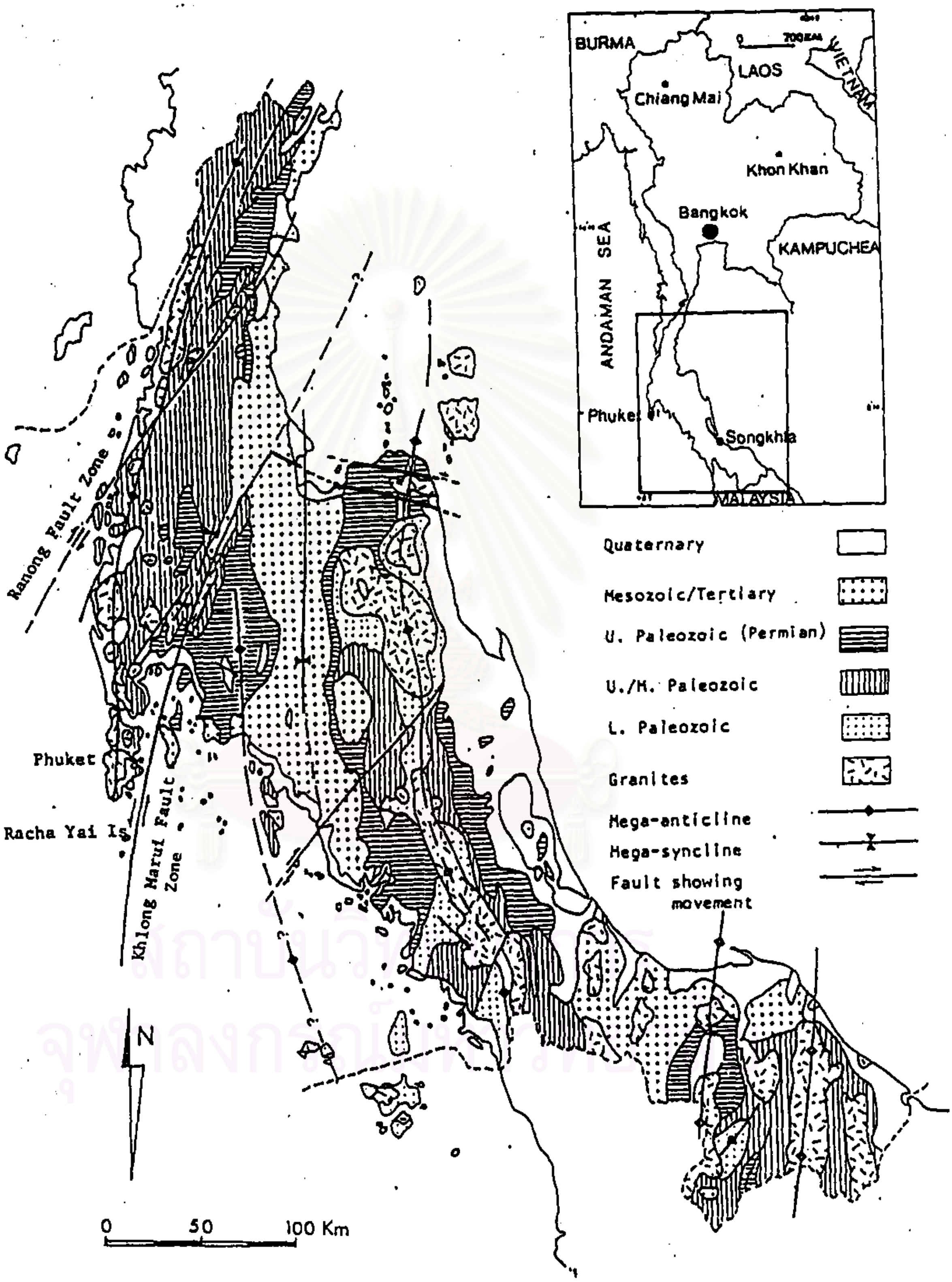


Figure 7.1. Regional tectonic elements in southern Peninsular Thailand (modified from Suensilpong, 1978).

Indochina Plates in the Permo-Triassic time and reactivated in the Late Cretaceous when western Burma collided with Shan-Thai.

On the bases of the geological observations and the $^{40}Ar/^{39}Ar$ geochronological data, Charusiri (1989) suggested that the Three Pagodas (NW trending) fault was intensely active between 77 and 46 Ma, and he also suggested that the Ranong-Khlong Marui fault zones were probably also strongly active during the same period between 82 and 41 Ma.

Structural Geology of the Khanom Area

In this study, an attempt has been made to reconstruct the structural evolution of the Khanom area using both megascopic and microscopic approaches. Most structural elements to be discussed occur throughout the area but they may differ somewhat in their appearance due to their reaction with the deformational stresses and grade of metamorphism. Various structural elements measured and described throughout the area include beddings, foliations, faults and joints.

Bedding planes (S_0) can be recognized in several outcrops where they are defined by alternating layers of varying composition which represent original sediment variation. Alternating bands of quartz-mica schists and mica schists commonly show distinct boundaries of rocks of differing compositions which reflect the original difference in detrital minerals, grain sizes and composition of the original rocks. Figure 7.2 shows S_0 of the Haad Nai Phlao Gneiss with interlayers of variable grain size between medium- grained equigranular and very coarse- grained porphyroblastic texture.

Axial-plane foliation/schistosity (S_1) and equivalent feature cleavage is the most prominent discordant foliation in the area. The axial-plane schistosity is defined by well oriented mica flakes and elongate quartz grains and opaque minerals. In many outcrops the axial-plane schistosity is almost parallel to the bedding (S_0), but can sometimes forms a small angle to bedding plane (Figure 7.3).

Figure 7.2. Interlayers of medium- and very coarse- grained gneissic texture indicate S_0 foliation of Haad Nai Phlao Gneiss. Pseudobedding (S-shape white band) result from advance stage of transportation of bedding. Occasional more competent members preserve isoclinal folds, which show S_1 and S_2 foliations.

Figure 7.3. Well-developed schistosity (S_1) and bedding (S_0) of mica-quartz schist in the Khao Yoi Schist units.

Late schistosity (S_2), or the younger schistosity, is characterized by slightly developed shear or slip plane. However, the platy minerals and elongate grains are well oriented planes in the high metamorphic region. A younger schistosity is prominently developed in many areas.

Measurements of the orientations of foliations and joints in rock units of the area were made by the author during field investigation. The data were computed and plotted (using Schmidt method of computing pole concentration and the equal area projection technique) using the "DIPS 3.0" software created by the Rock Engineering Group of the Department of Civil Engineering, University of Toronto (Diederichs and Hoek, 1989). The mapped area has been divided into six domains for purpose of describing its structural development. These domains are distinguished from each other by lithological differences or rock units (Figure 7.4).

Foliations

As shown in Figure 7.5, the major foliation in the region has a general NNW-SSE orientation. Considering only the measurements from the gneissic rocks, the poles to foliation are more variable in the Haad Nai Phalo than in the other domains. From the stereographic projection plots, only one major foliation may be defined in the study area : NNW-SSE striking with a steep to vertical easterly dip. The value of these orientation is a moderate difference in the average dip angles in the Haad Nai Phlao Gneiss with 56°-78° (main domain) and 72°-80° (small domain). The average value of dip angle of the Laem Thong Yang Gneiss is a small difference whereas a large difference in the Khao Dat Fa Granite (49°-78°).

The late schistosity (S_2) occurs commonly within the outcrop of the Haad Nai Phlao and Laem Thong Yang Gneisses. S_2 morphology also varies with rock type. In most rock types, S_2 are a domainly slaty and crenulation cleavages defined by continuous mica flakes in the Haad Nai Phlao Gneiss, whereas the Laem Thong Yang

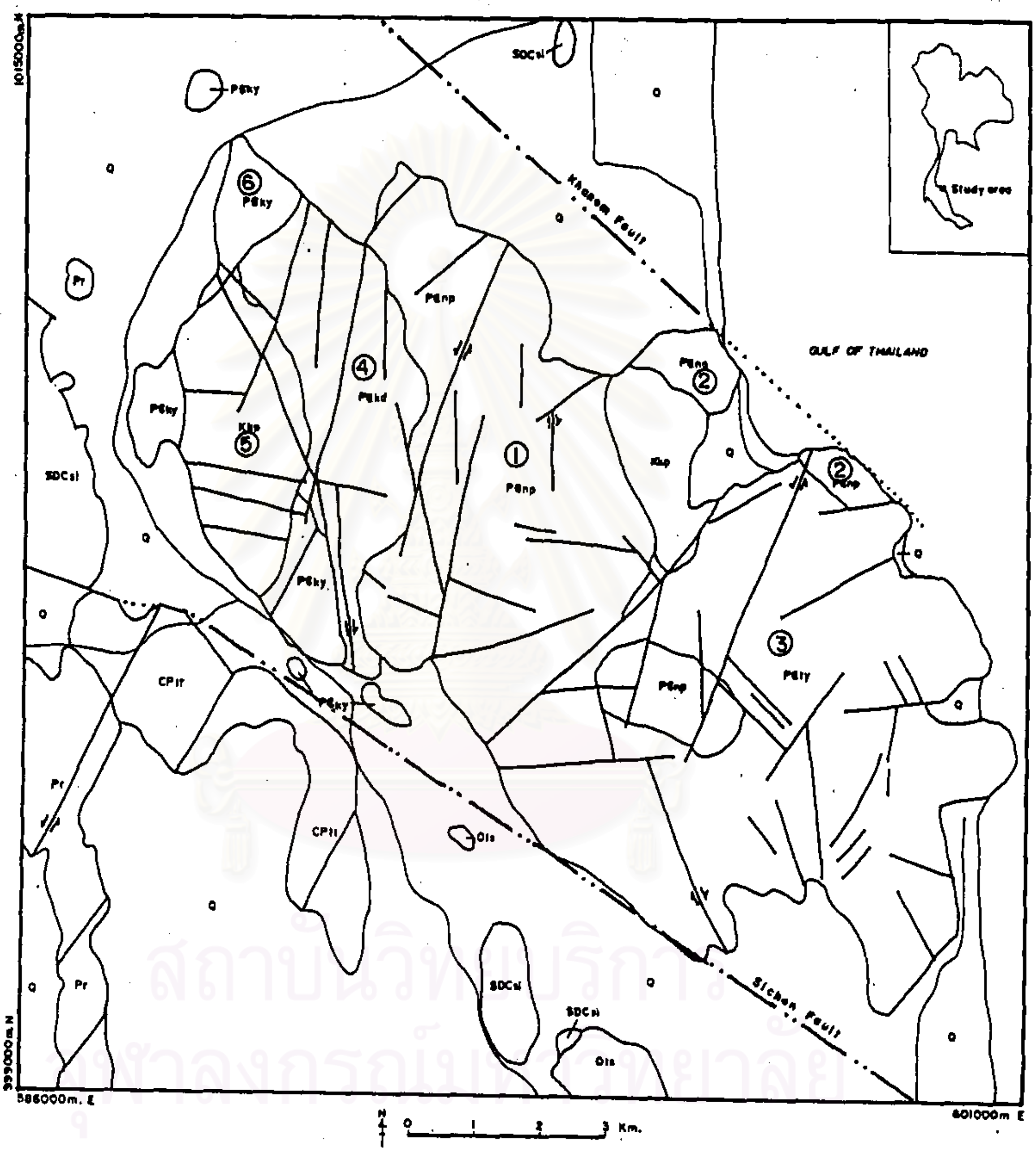


Figure 7.4. Simplified geological map showing six structural domains in the Khanom Gneissic Complex region. Symbols as 1=Haad Nai Phlao (main), 2=Haad Nai Phlao (small), 3=Laem Thong Yang, 4=Khao Dat Fa, 5=Khao Pret, 6=Khao Yoi. Legend as in Figure 2.1.

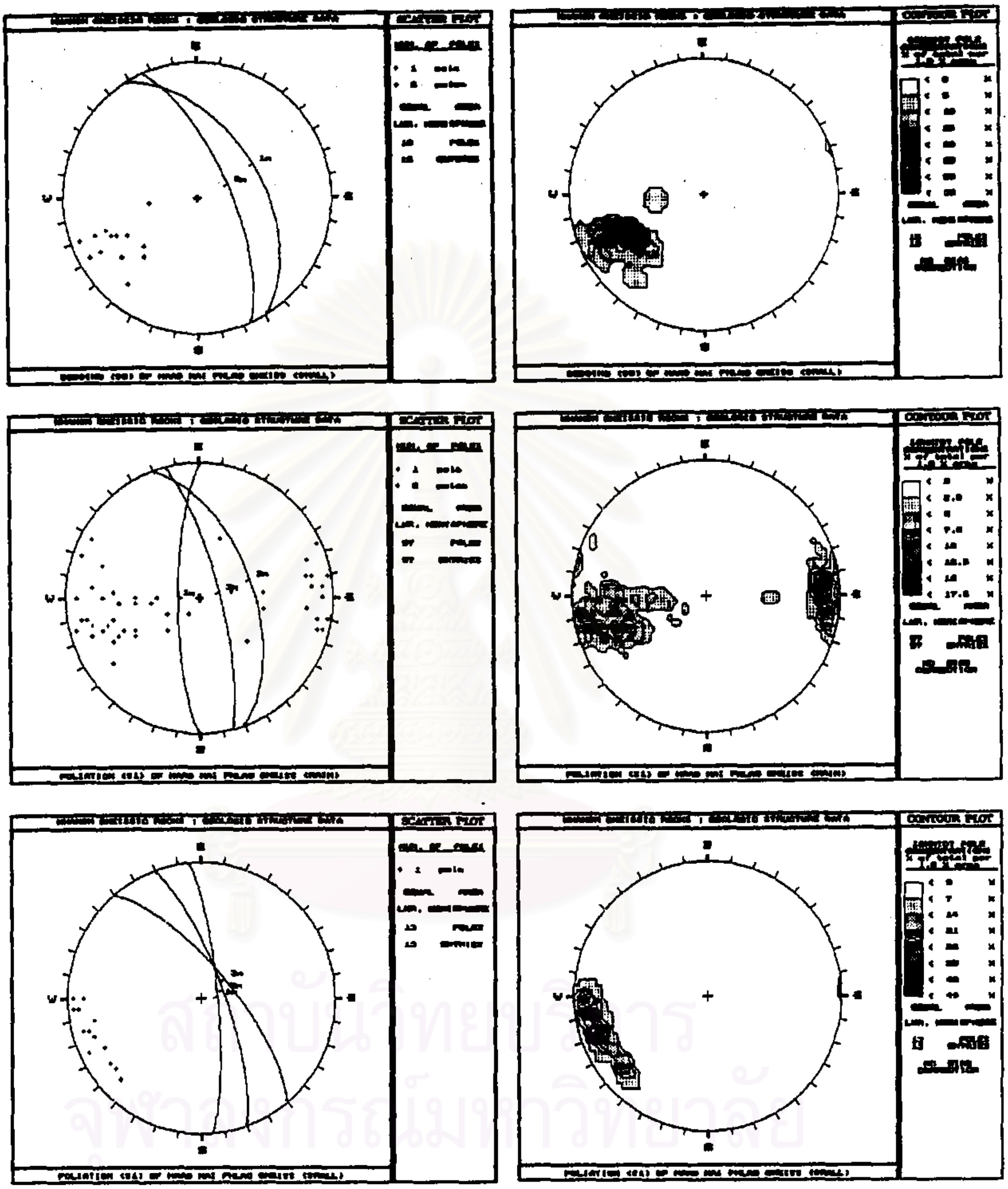


Figure 7.5. Equal area plots of poles to beds and foliations (scatter and contour) in the Khanom area.

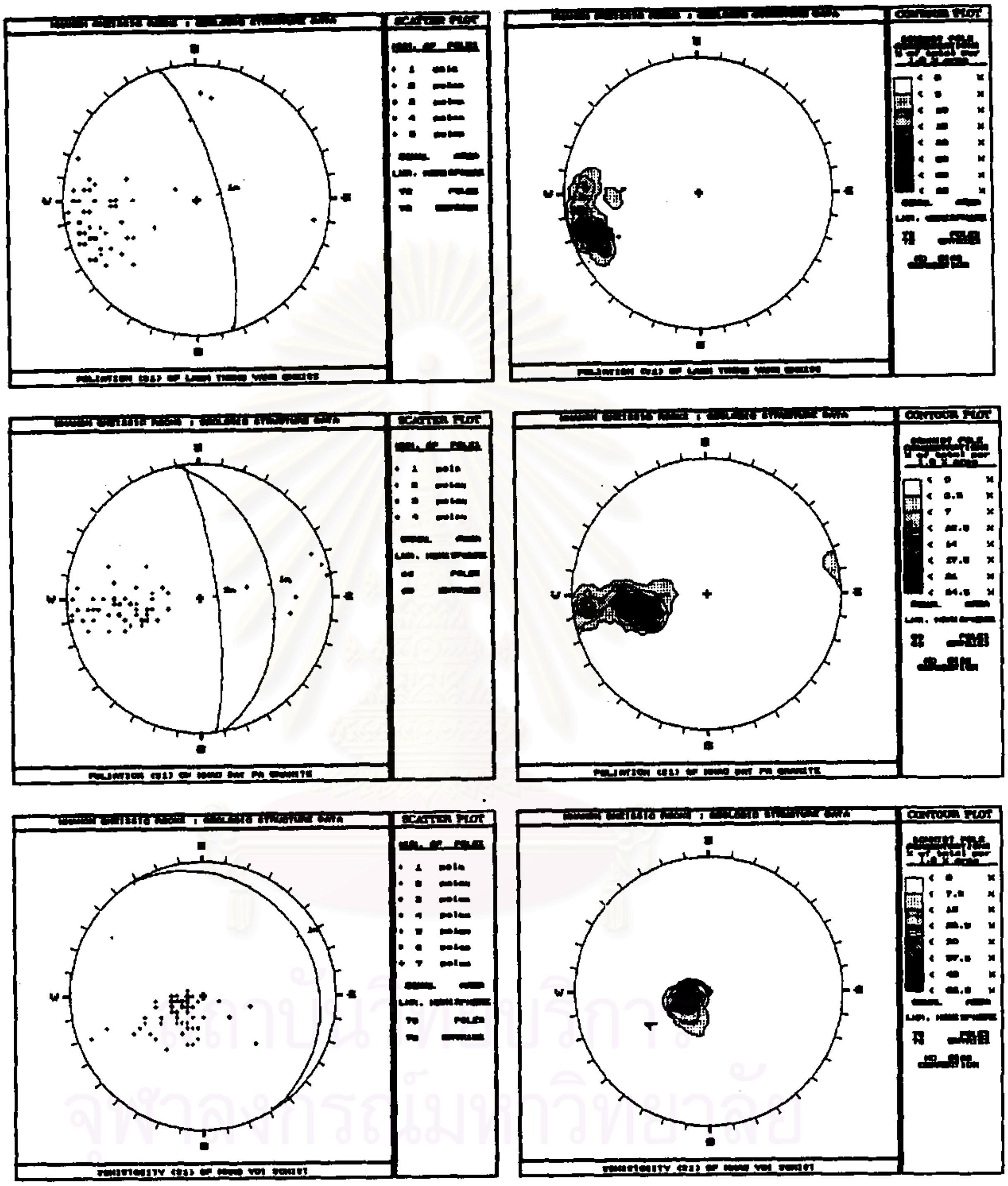


Figure 7.5. (continue).

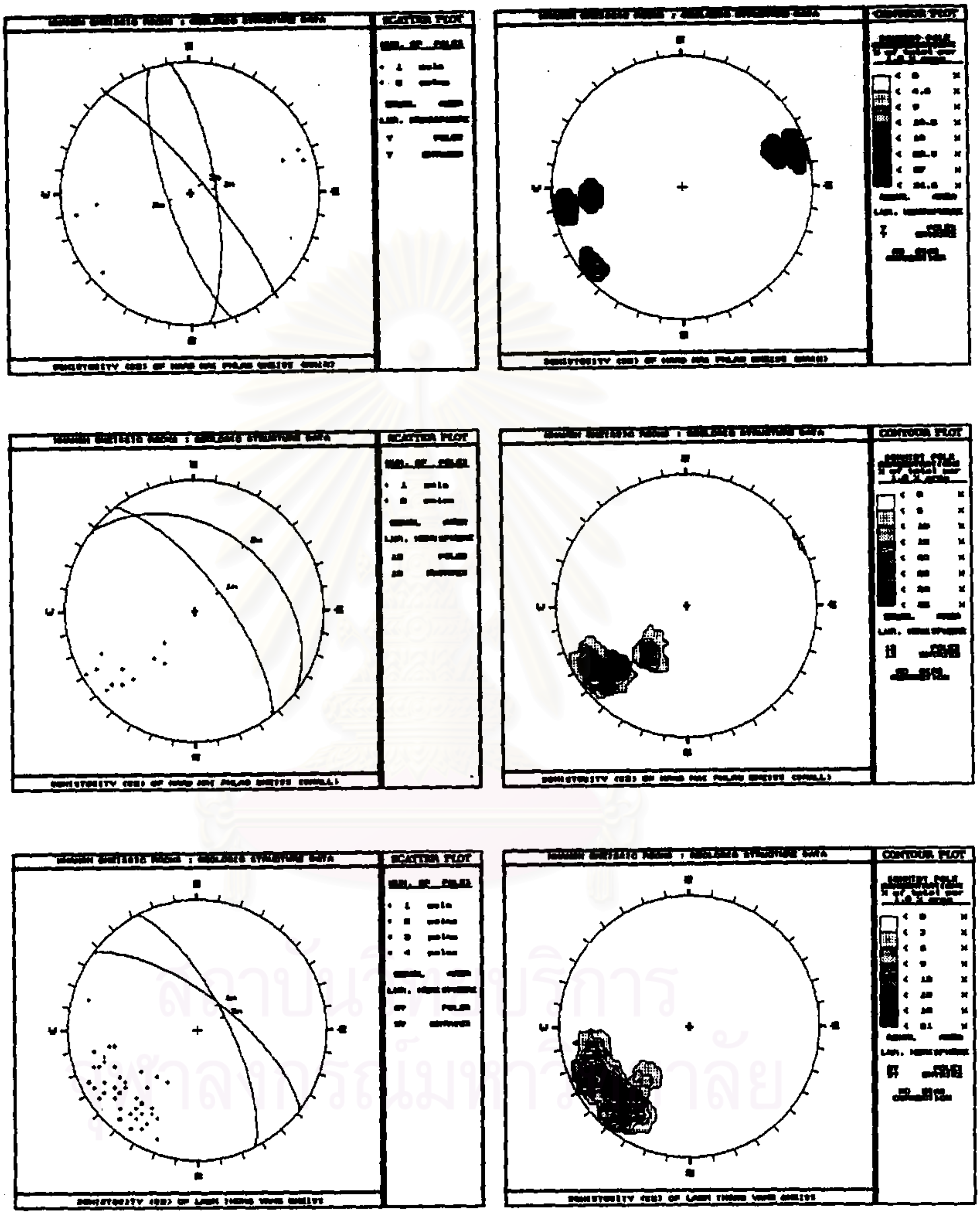


Figure 7.5. (continue).

Gneiss is characterized by slip cleavage. This schistosity is generally oblique to the earlier foliation and shows a consistent asymmetry with S_1 that is suggestive of sinistral shear bands. The stereographic projection plots show a general NW-SE orientation. The S_2 value of dip angle of the Haad Nai Phlao and Laem Thong Yang Gneisses are approximately 40°-80° and 60°-70°, respectively.

Folds

Folding is a common feature observed in this area. The presence of crenulation foliations, " S " and " Z " folds, kink bands and mineral lineations suggest at least two phases of deformation. The minor " S " and " Z " folds may indicate that they belong to an earlier folding event whereas mineral lineations may indicate that they belong to the most recent deformation event.

Rocks of the Haad Nai Phlao Gneiss in the main domain show several types of folds such as tight, overturned and isoclinal folds, as well as ptymatic fold of pegmatite and aplite. The contoured plot of poles to bedding and foliation displays a distinct clustered distribution corresponding to the plunging trend (Fold axis,F.A.S_0=348°/22°, F.A.S_1=350°/23°). This is consistent with isoclinal fold recognized in the field (Figure 7.7). The fold axis in the small domain of the Haad Nai Phlao Gneiss trend north-northwest as shown by an equal area projection for the area.

In the Khao Yoi Schist domain, the prominent feature is a deceptive structural simplicity with homogeneous, subvertical bedding and schistosity. Macroscopic structure is distinct recumbent fold recognizable as bed-schistosity horizontal strata. The fold has axial planes that dip gentle northeast, with horizontal to gentle plunging axes trending north-northwest (F.A.=352°/11°).

Figure 7.6. Shear planes (S_2) due to secondary stresses cross cut foliation (S_1)in the Laem Thong Yang Gneiss that is sinistral movement near Ban Huai Sai, with $S_1 = 010°/70°$, $S_2 = 350°/60°$.

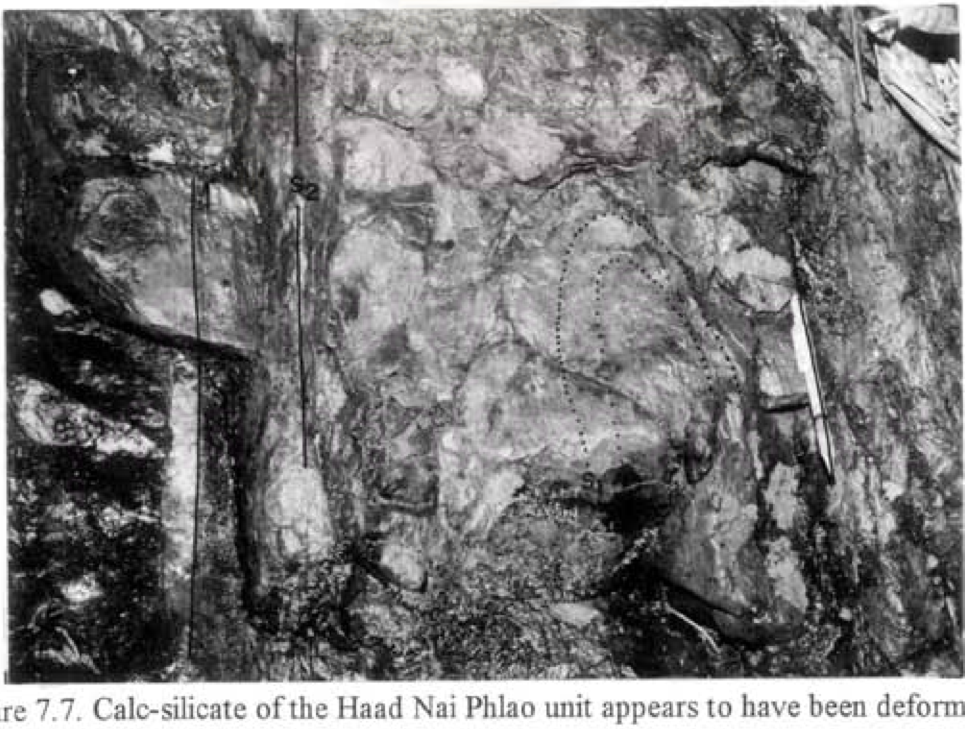


Figure 7.7. Calc-silicate of the Haad Nai Phlao unit appears to have been deformed by at least two deformation events. S_0 and S_1 are isoclinal fold, S_2 is parallel to axial plane with 360°/80° attitude, similar to those of S_0 & S_1 fold axis.

Figure 7.8. Photomicrograph of the Haad Nai Phlao Gneiss showing isoclinal fold structure of S_1 foliation with slightly-rotated garnet, is cut by S_2 foliation as characterized by well developed arrangement of platy biotite.

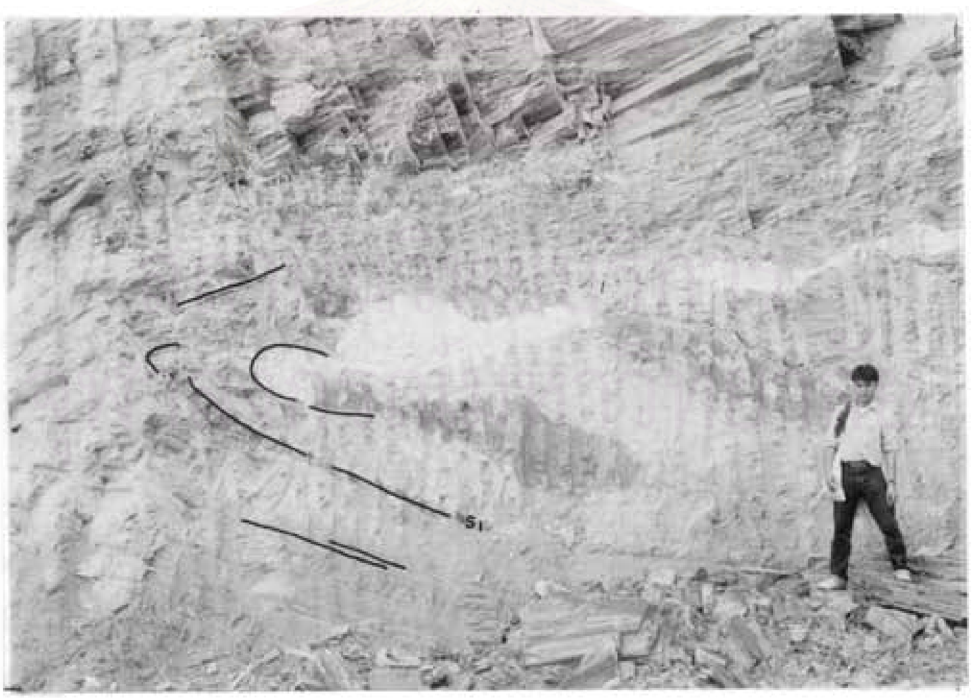


Figure 7.9. A tractor-cut exposure showing a large recumbent fold of the Khao Yoi Schist showing north plunging fold axis, Mr. Wattana Tuteechin as a scale.

Faults

The NNE-, NNW- and E- trending fault systems can be observed throughout the area from aerial photographic and airborne radiometric maps, the NNE- trend being the most common. It shows that the NNW-and E- fault systems have been offset by the NNE- fault system. A number of faults have been identified across the mapped area. In the most cases these are minor, but some have a significant effect on the deformation and distribution of the rock units. The eastern boundary between the Haad Nai Phlao and Laem Thong Yang Gneisses is a NE-trending fault line, which is not restricted to valleys, however, forms part of the Khao Luang mountain. On the basis of field observations, the NNE- fault is the principal left -lateral strike-slip fault, whereas the NNW- fault is a conjugate right-lateral strike-slip fault. Their orientations can be related to the strain ellipsoid of a dextral simple shear model, that is with N-S compression and E-W extension. A NNE-trending fault in the southwestern part of the area extends from unmetamorphosed Upper Paleozoic rocks to high grade metamorphic complex, and shows left lateral offsets.

Joints

The tension joints arranged en echelon is found in the field at the Khao Yoi Schist. They are commonly developed adjacent to major faults. Offset of quartz veins forms indicate that direction of movement of fault is left lateral (sinistral) subhorizontal shear forces (Figure 7.11), almost parallel to original beddings.

From rosette diagram plots (Figure 7.13) of joint planes in the study area, although joint concentration sets are more difficult to delimit in the plots than the foliations, they can be assigned to NNE-SSW set which is the major joint system in all units except the Khao Pret Granites, which mainly occurs as the E-W joint set. The other minor joint set, the NNW-SSE, can be observed locally in the field. Orientations of pegmatite/aplite dykes and quartz veins in the area can be divided into three groups in order of abundance as NNW-SSE, NNE-SSW and E-W orientations.

Figure 7.10. The NNW- trending fault in the Haad Nai Phlao Gneiss showing right lateral strike-slip fault at Khlong Tha area (looking west), fault plane=345°/80°.

Figure 7.11. En echelon quartz veins in mica-quartz schist at Km. 0+850 road to Khao Dat Fa mountain, with attitude 345°/50° (looking east).

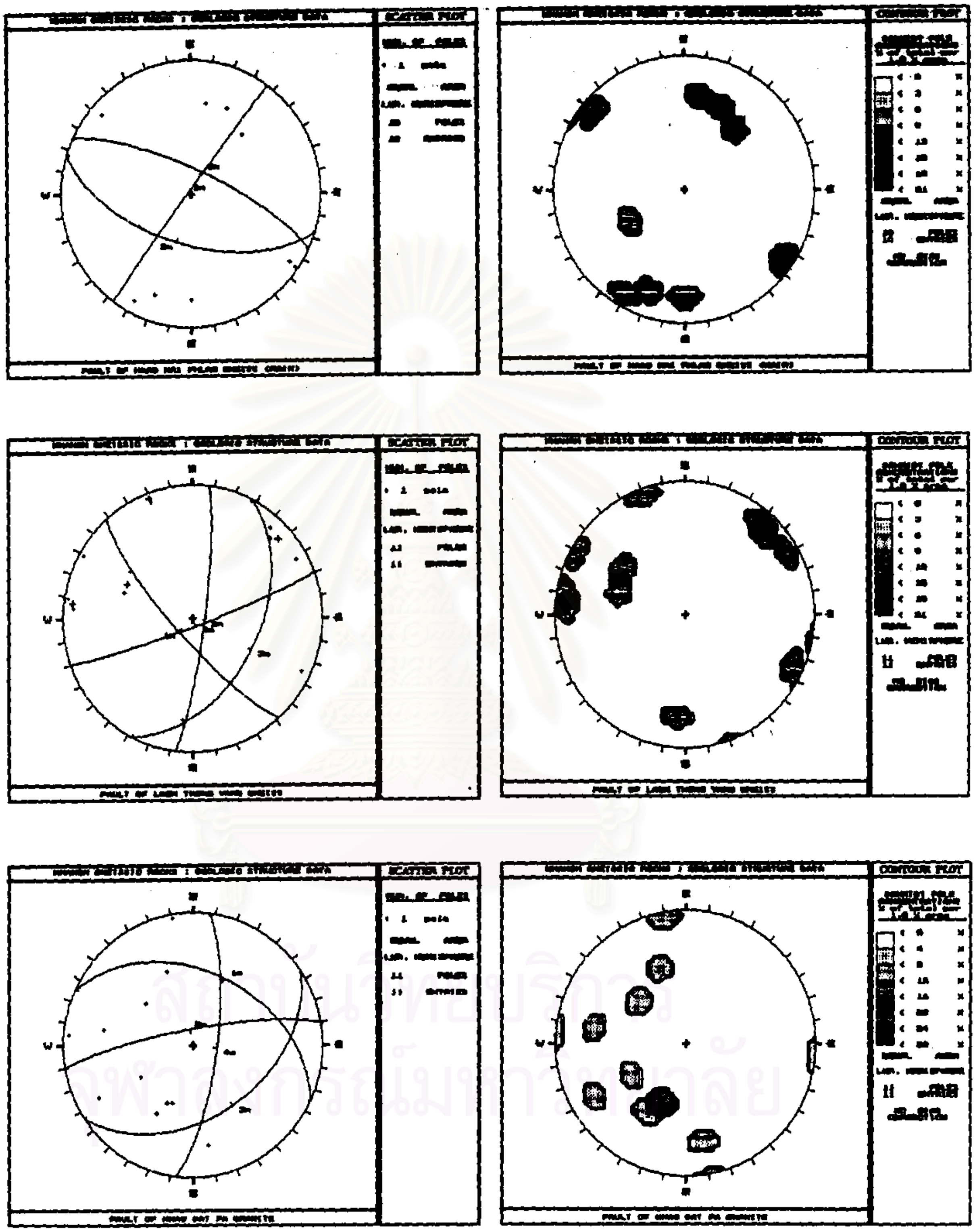


Figure 7.12. Scatter and contour equal area projection plots of faults of the study area.

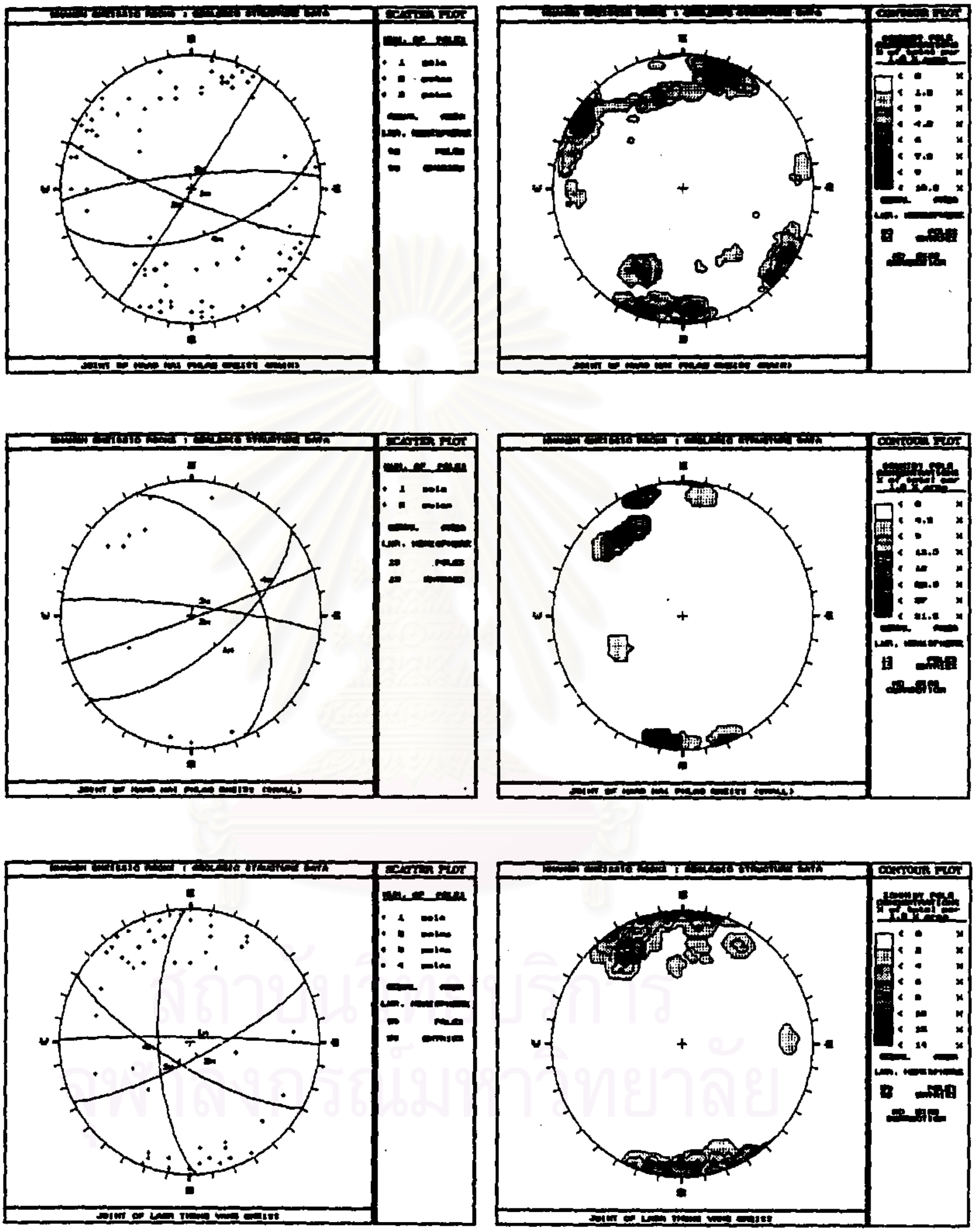
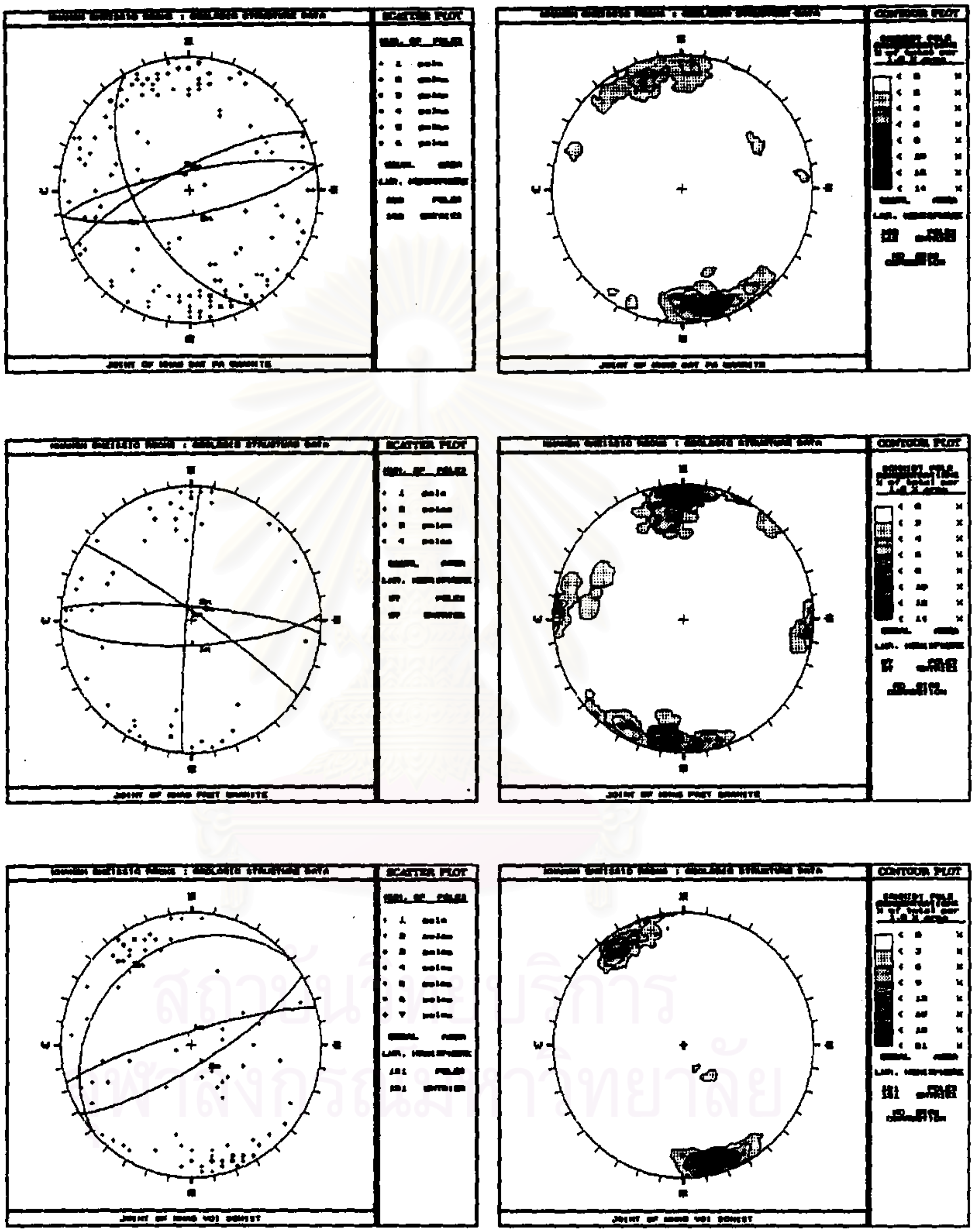


Figure 7.13. Scatter and contour equal area projection plots of joints in the Khanom area.



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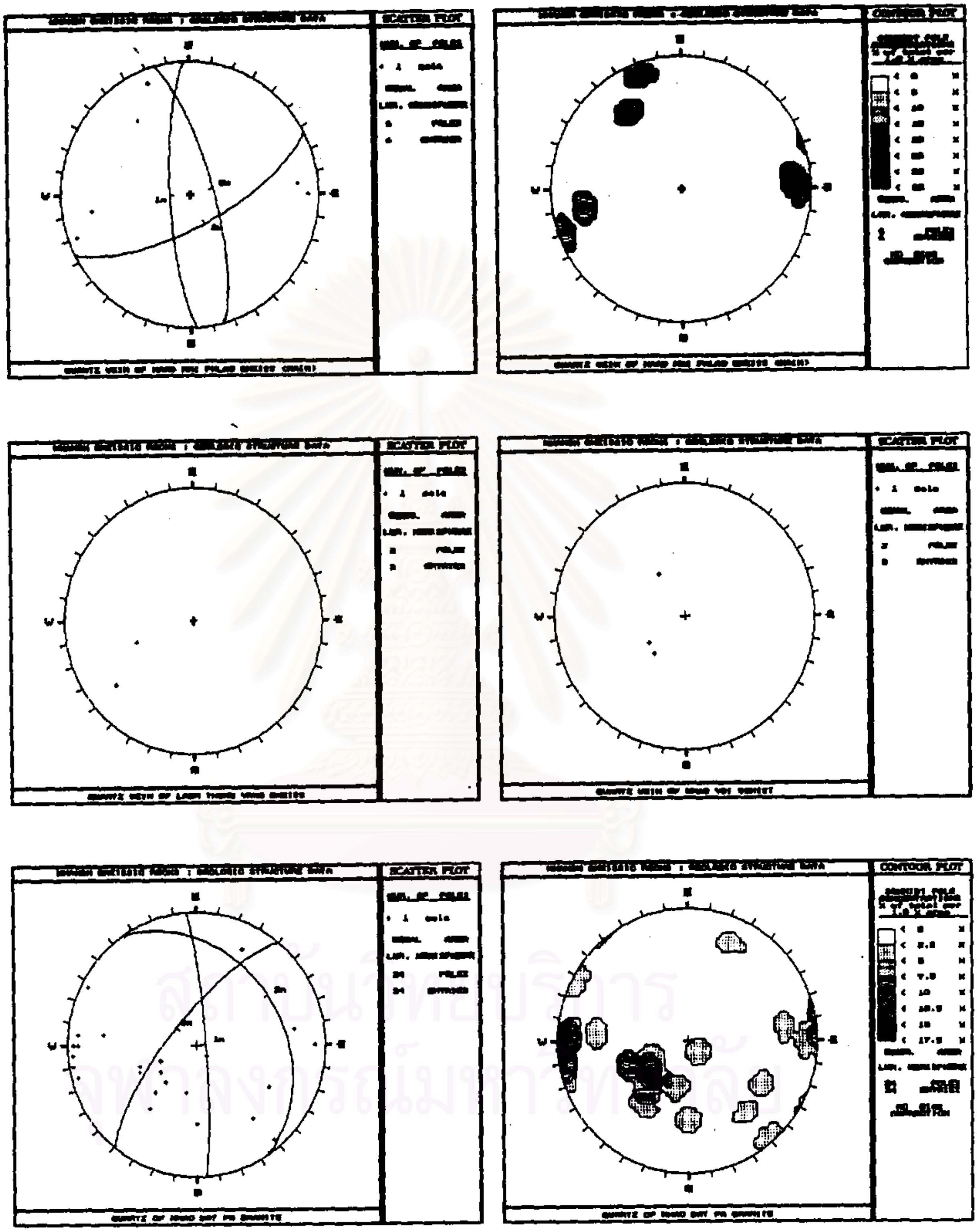
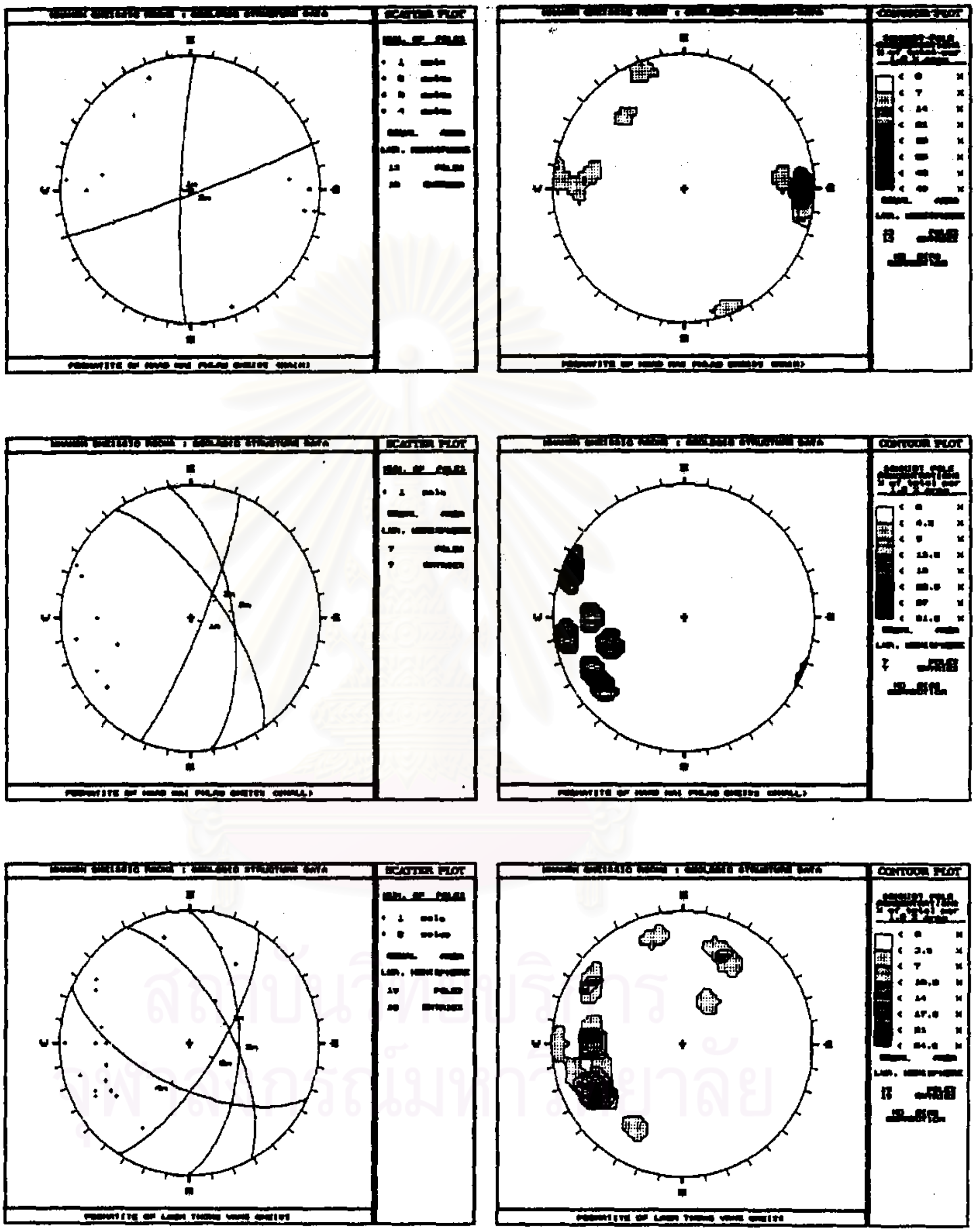


Figure 7.14. Scatter and contour equal area projection of quartz and pegmatite veins of the study area.



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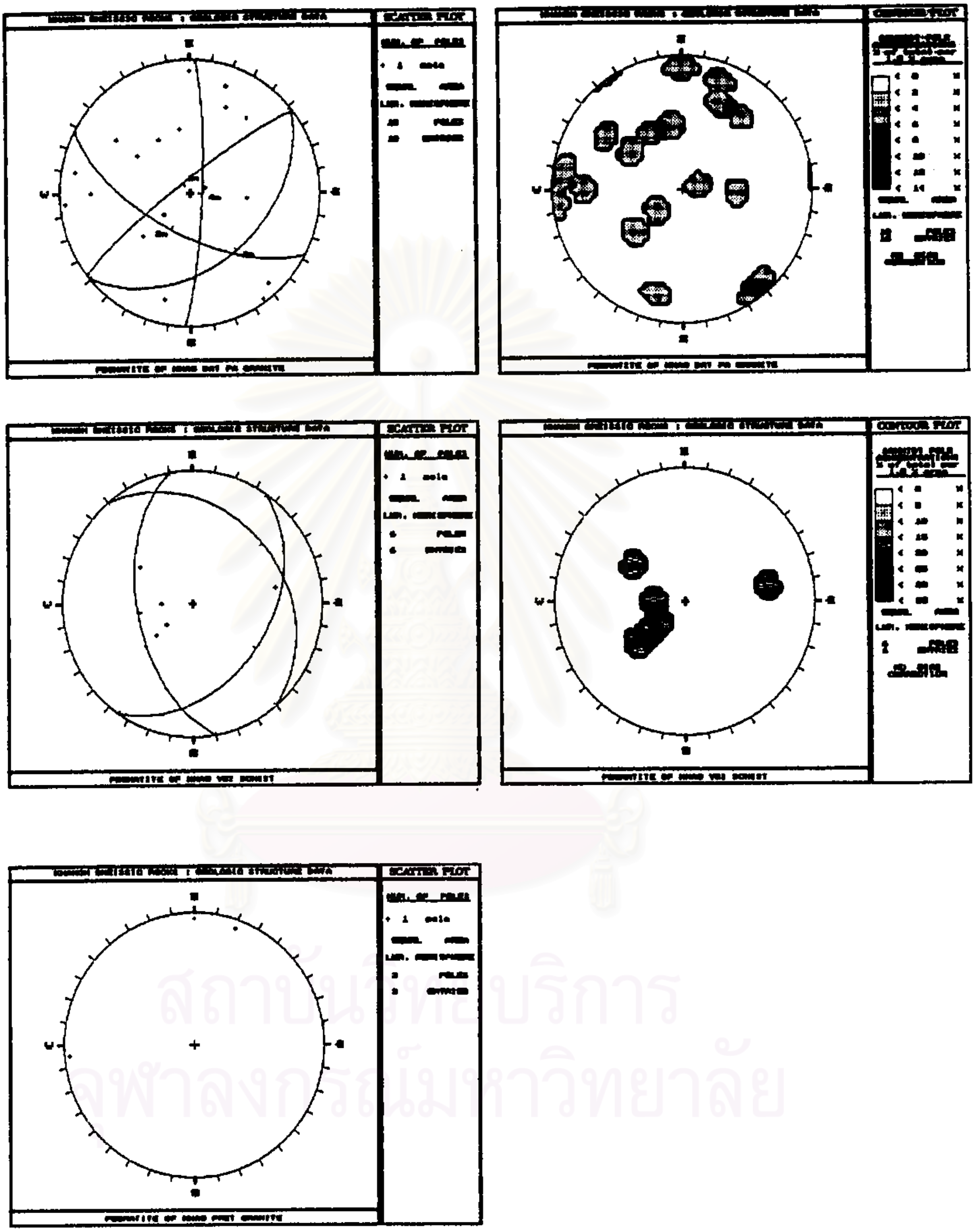

Figure 7.14. (continue).

Table 7.1. Conclusion of geologic structure attitude of the Khanom Gneissic Complex (Strike/dip).

DOMAIN	S0	S1	S2	JOINT	FAULT	Q.V.	P.V.
Haad Nai Phlao Gneiss (Main) (1)	355/65	180/77 340/57 347/77 F.A.=350/23	352/73 162/75 320/80	034/90 110/82 265/81 073/61	217/88 107/59 295/75	178/77 345/75 063/70	182/84 070/88
Haad Nai Phlao Gneiss (Small) (2)	330/50 337/70 F.A.=342/15	343/77 317/72 350/80 F.A.=016/65	323/70 308/37	051/66 070/80 277/84 335/45	020/45 010/85	340/40 345/50	023/82 325/70 350/63
Laem Thong Yang Gneiss (3)		340/74 345/75	308/68 331/71	271/87 063/80 120/75 178/70	138/78 008/82 028/47 070/85	350/60 360/70	331/64 360/58 033/72 115/62
Khao Dat Fa Granite (4)			350/44 352/81	259/78 079/75 244/76 150/56	295/43 260/80 056/44 007/75	356/84 326/34 220/73	233/82 050/40 298/60 002/87
Khao Pret Granite (5)				088/75 276/82 184/87 305/85	060/65	110/85	090/85
Khao Yoi Schist (6)		340/15		254/82 059/78 229/26	050/85 130/60	325/30 060/30	320/30 170/55 035/40

Remarks
F.A. = Fold axis
Q.V. = Quartz vein
P.V. = Pegmatite vein