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Structure Geology of the Khanom Gneissic Complex, Nakhon Si Thamamarat Province, Southern Thailand

Suwith Kosuwan[1] & Punya Charusiri [2]

[1] *Geological Survey Division, Department of Mineral Resources, Rama 6th Road, Ratchathewi, Bangkok 10400*
[2] *Department of Geology, Chulalongkorn University, Phaya Thai Road, Bangkok 10400*

ABSTRACT

The Khanom gneissic Complex (approximately 225 sq km) is situated in the northern part of Nakhon Si Thammarat Province, southern Thailand. Various formations of the Complex have been recognized and are formalized as the Haad Nai Phalo gneiss, occurring in the central of main range, is equigranular biotite± sillimanite gneiss and calc-silicate occasionally. The Khao Yoi schist consists mainly of mica±garnet schist, quartzite and lenses of calc-silicate and marble. It covers the western rim of the Khao Dat Fa mountain. The Laem Thong Yang gneiss occurs in eastern and southern parts of main range,consists principally of porphyroblastic biotite gneiss with augen texture, and is later cut by fine-grained biotite gneiss. The Khao Dat Fa granite, which is well outcropped in the peak main mountain, is generally characterized by fine-to medium-grained, equigranular, biotite granite with well-defined orientation of flaky minerals. The youngest rocks in the complex area are assigned as the Khao Pret granite, which consist of biotite granite, medium-grained, equigranular, and can be geographically subdivided into 2 terranes, as the western and eastern terranes.

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, 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. 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. S1. which marks the first phase of deformation, is identified by well oriented mica flakes and elongate quartz, feldspar and garnet grains, which generally forms a small angle (10o to 20o) to bedding. It is inferred from several evidences that the S1 foliation is, to some extent, parallel to the NW-trending major fault.

S2 is identified by the development of crenulation cleavage as defined by biotite, muscovite and sillimanite 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 ralated 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 (S3) 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.

INTRODUCTION

The Khanom and neighboring area, ocated between the eastern part of Surat Thani nd northern part of Nakhon Si Thammarat rovinces, is approximately 780 km south of Bangkok, between latitudes 9° 02' to 9° 43' N nd longitudes 99° 16' to 99° 56' E. The nteresting area is situated in high mountainous region with complicated geology. The main peak mountain is Khao Dat Fa (732 meters msl), and the highest peak is Khao Luang that about 814 meters. The oldest rocks are high-grade metamorphic complex of inferred Precambrian age, including gneiss, schist, calc-silicate, quartzite and marble, which outcrop in the southern part of Khanom town. This complex group is subsequently cross-cut by Mesozoic granite with equigranular medium-grained texture. Unless specified, the terms "granitic rocks" and "granitiods" are loosely applied herein to represent the rocks with/without foliation which have the gross mineralogical composition; i.e., quartz and feldspar, similar to granite "sensu stricto". The complex is surrounded by clastic and non-clastic Lower Paleozoic rocks, and the granite and leucocratic granite expose outside to the south form as northern extension are some the so-called Khao Luang Batholith (Charusiri, 1989). Quaternary deposits cover most of the low lands and shore-line areas. Tectonically, the Khanom Complex is situated in the so-called Shan- Thai- Malay microcontinental block (Bunopas,1981; Charusiri, 1989).

GEOLOGY OF THE KHANOM GNEISSIC COMPLEX UNITS

The very detailed geology was first described by Kosuwan (1996) and the application of airborn-radiometric data to the mapped area was very recently performed by Charurisi et al. (1997). On the bases of differences in mineralogical composition, microstructure and texture, the Khanom gneissic complex can be classified into five units and delineated in the map.

The first unit is referred herein as the Haad Nai Phlao gneiss, and crops out mainly in the central portion of the main mountain with additional minor masses occurring in the northeastern part of the area and at upper parts of high mountains.

The second unit is referred to as the Khao Yoi schist, and is well exposed at the western rim of the main mountain.

The third unit herein called the Laem Thong Yang gneiss, and occurs chiefly in eastern and southern parts of the mountain.

The forth one is referred as the Khao Dat Fa granite, which is well-outcropped at the peak of the main mountain in the central part of the area. The fifth unit, herein called the Khao Pret granite, is largely observed in eastern and western parts of mountain.

Distribution of these five units is shown in Figure 1. No major breaks are recognized among the metamorphic units and are inferred to be conformable. There are also some minor intrusions minerallogically equivalent to leucocratic granite but their aerial extent are so small that they cannot be delineated in the map. In addition, this type of granite is very friable and exhibits foliation parallel to the schist, making the classification of this granite more difficult.

Haad Nai Phlao gneiss

The rock is mainly biotite gneiss and biotite-sillimanite gneiss, occurring in alternating layers, which posses differences in grain size (ranging from fine to coarse grains). The internal layers range in thickness from a few tens of centimeters to a few meters. It is noteworthy that the medium- to coarse-grained gneiss is remarkably porphyroblastic texture whereas the fine-grained gneiss is commonly equigranular affinity. These gneisses are cut by deformed pegmatites and aplites. The pegmatites, ranging in thickness from 10 to 150 cm, consist principally of large crystals of quartz, K-feldspar and muscovite with sparsely distributed fine- to medium- granied garnet (maximum size about 2 cm). The aplites, varying from 2 to 50 cm thick, comprise similar mineral constituents to the pegmatite.

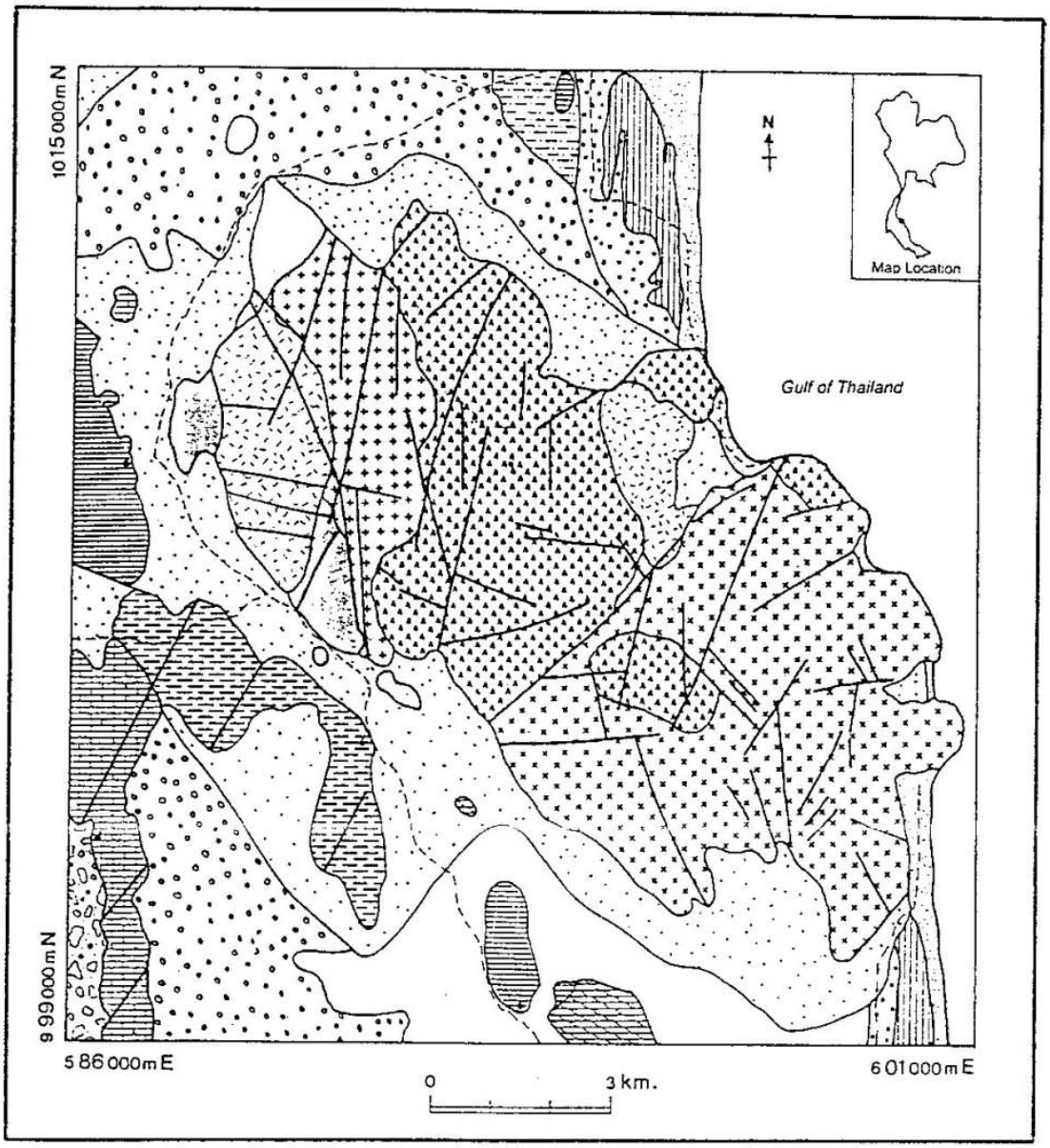

Figure 1. Geological map of the Khanom area (Quaternary Geology modified from Chaimanee, 1992).

The aplites usually exhibit fine-grained texture and sometimes spatially associated with pegmatites. In a number of occurrences, the gneiss is outstandingly founded interlayered with calc-silicate rocks. Calc-silicate rocks are fine- grained, finely laminated, with white to green and purplish-brown lamellae.

Khao Yoi schist

The unit consists commonly of schists and quartzites, with lenses of calc-silicate and marble (up to 2 m thick) occasionally intercalated in schist. The schists, which form the lower part of the unit, comprise yellow coloured mica schist, light yellow muscovite-garnet schist and yellowish brown quartz-mica schist. The quartzites, the upper part, include greyish white to brownish yellow quartzite, brownish grey micaceous quartzite and dark brown fine-grained quartzite. The overall thickness of schist is about 10 m. Field investigations indicate that quartzites have been underlain by schists, and the actual contact between the two rocks has been found at Khao

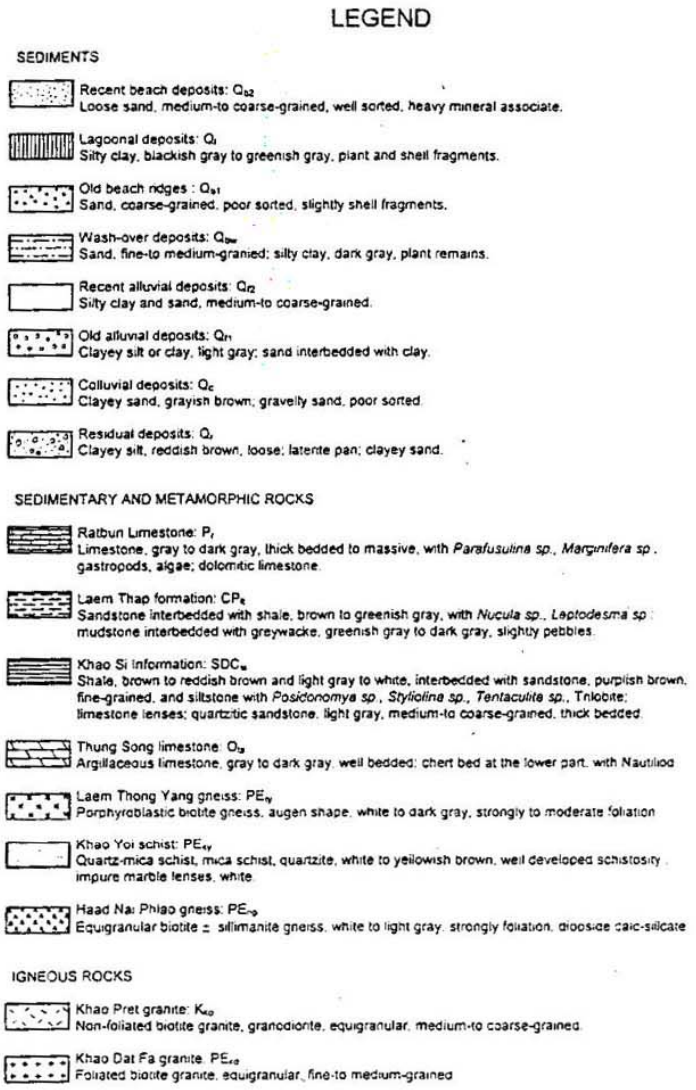

Figure 1. (continue).

Yoi quarry (earth open pitting). Howover, the contact with Haad Nai Phlao and the other gneissic rocks are observed.

The lower part of the Khao Yoi schist is interrupted by unit occurring as fine- to medium- grained leucocratic granite intrusion, and the schistose rocks and carbonate lenses were thermally metamorphosed to become spotted schist, schistose hornfels and skarn

rocks. The granitic rock, itself, exhibits metamorphic fabric exemplified by a well-developed foliation parallel to schistosity (S1) of the schist. Leucocratic granite, as its name denotes, is also foliated and typically whithish in colour because of lack of ferromagnesian minerals.

Laem Thong Yang gneiss

This unit consists principally of biotite gneiss, with quite abundant alkali feldspar megablasts and moderate to strongly foliation. The matrix foliation, outlined mainly by elongate, lenticular aggregates of fine-grained quartz and biotite, wraps around the megablasts. It shows augen tails of fine-grained, recrystallized mineral aggregates which indicate sinistral sense of movement. In the field at Laem Phlai Dam area, the deformed aplitic rocks (25 cm max. thickness) cut porphyro-

blastic gneiss, and the late stage, veinlets of undeformed pegmatite cross cut both rocks as well as have pelitic xenoliths (biotite-feldspar inclusions) and quartz lumps. Composition of pegmatites includes large grains of quartz, K-feldspar, muscovite and tourmaline. The aplitic rocks comprise similar minerals to the pegmatite, both veins with quite densely fine grained garnet. The porphyroblastic gneiss is cut parallel to subparallel to the main foliation by younger- phase, fine-grained, equigranular, biotite gneiss, before deformation by early tectonic event.

So far the nature of the relationship between the Haad Nai Phlao gneiss and the Laem Thong Yang gneiss is not clear.

Khao Dat Fa granite

This granite is generally characterized by well orientation of platy minerals including biotite. The biotite is the major mafic mineral. In general Khao Dat Fa granite is characterized by fine- to medium- grained, equigranular, biotite granite. Garnet pockets are commonly seen. The garnet is reddish brown in colour and its size varies from 3 to 5 mm. This rock is typically slightly foliation. Structural trends are generally north-south and moderately to steeply dipping. The pegmatites have been found cutting this granite. There is no evidence of foliation of platy minerals such as biotite and muscovite which indicates that the pegmatites must be emplaced after the strong deformation event.

Khao Pret granite

This unit is distinguished from the others by the non-foliated feature. Apparently it represents a new main phase, or the younger granitic rock unit, emplaced in this area. The rocks in the complex area which herein are assigned as the Khao Pret granite can be geographically subdivided into 2 terrains, namely the western terrain - light grey biotite granite, and the eastern terrain - pale grey biotite granite gradational to minor- phase granodiorite, the latter collected from a float and interpreted as inclusions in granites. These rocks are usually fine- to medium- grained, phaneritic in texture.

From this current study, it is considered that the Khao Pret granite crosses cut the Haad Nai Phlao gneiss and the Laem Thong Yang gneiss, at Khlong Tha and Khlong Phlao, respectively. Unfortunately, it is quite difficult to observe the contact with the others, as Khao Dat Fa granite, due to the scarcity of exposures and thick top soils.

STRUCTURES IN THE KHANOM GNEISSIC COMPLEX

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 somewhat differ 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.

Measurements of the orientations of foliations and joints in rock units of the area were made during field investigation. The data were then 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 explaning its structural development. These domains are distinguished from each other by lithological differences or rock units (Figure 2).

Foliations

As shown in Figure 3, 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

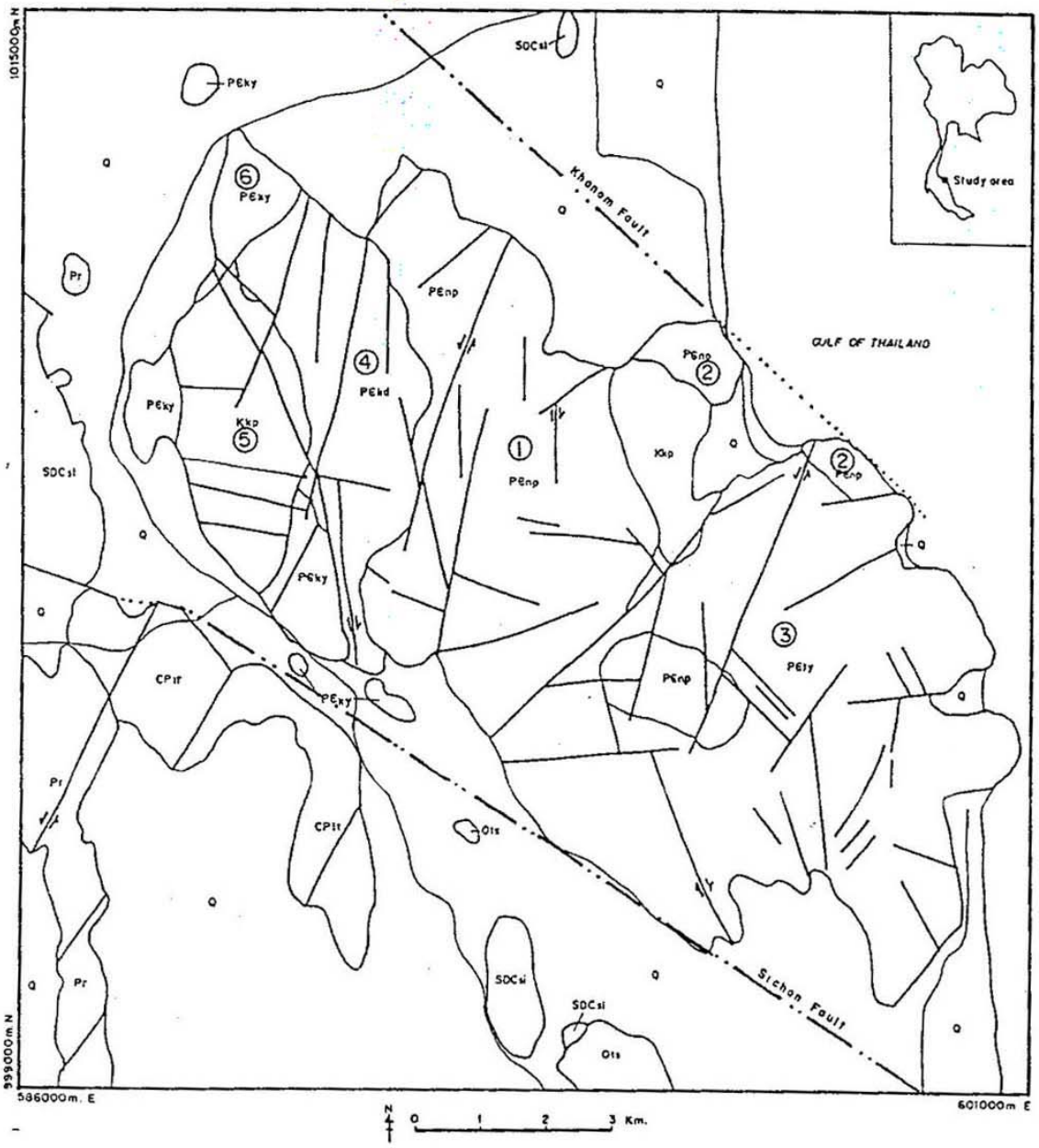

Figure 2. Simplified geological map showing six structural domains in the Khanom gneissic Complex region. Symbols as 1=Haad Nai Phlao (main), 2=Haad Nai Phlao (small), 3=Laem Thong Yang, 4=Khao Dat Fa, 5=Khao Pret, 6= Khao Yoi. Legend as in Figure 1.

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 was observed 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 generally a domainly slaty and crenulation cleavages defined by continuous mica flakes in the Haad Nai Phlao gneiss, whereas the Laem Thong Yang gneiss is characterized by slip cleavages. This schistosity is generally oblique to the earlier foliation and shows a consistent asymmetry with S_1, suggestive of sinistral shear bands. The stereographic projection plots show the general NW-SE orientation. The S_2 values of dip angle of the Haad Nai Phlao and Laem Thong Yang gneisses are approximately 40°-80° and 60°-70°, respectively.

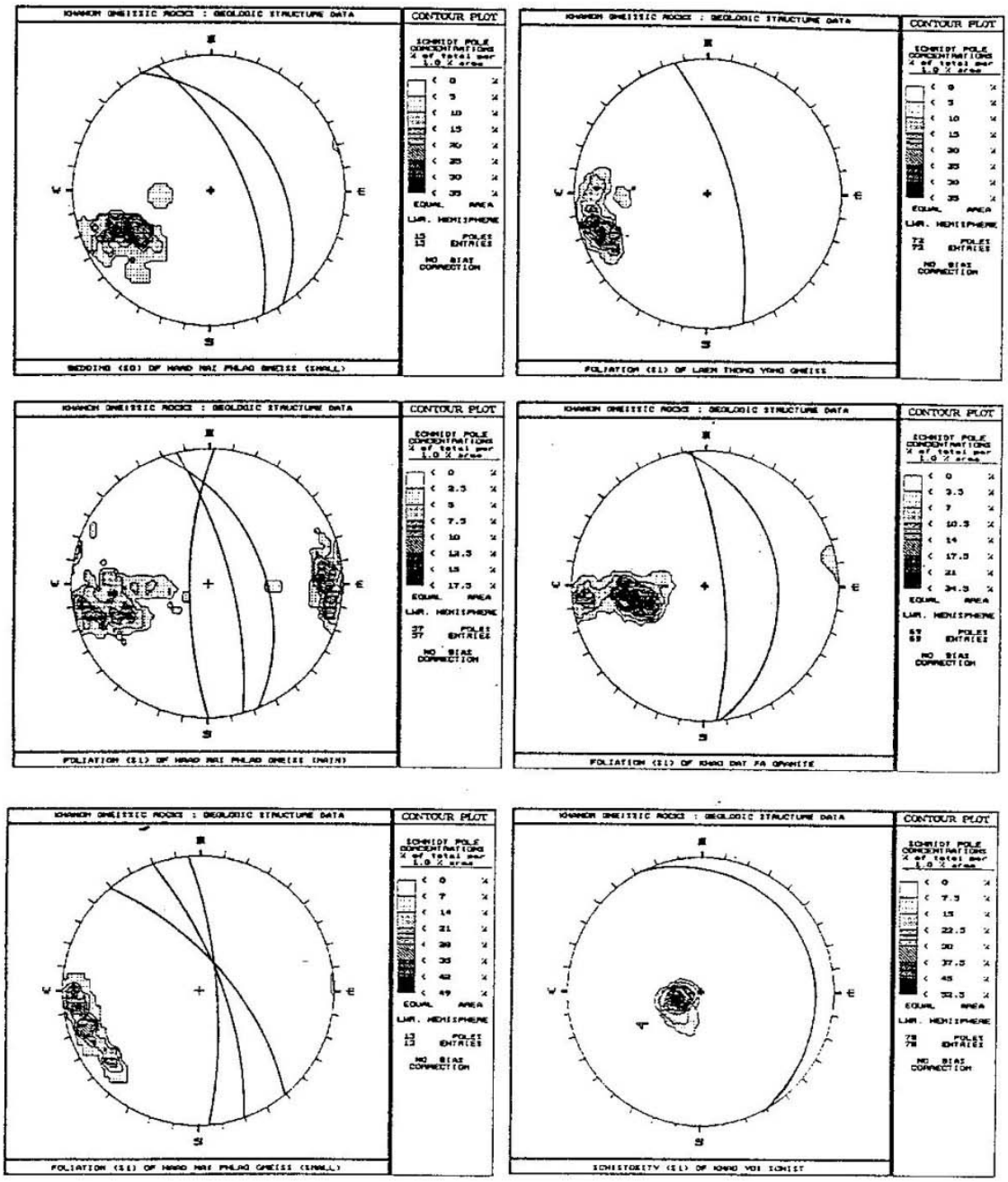

Figure 3. Equal area plots of poles to bedding and foliations in the Khanom area.

Fold

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 display distinct clustered distribution corresponding to the plunging trend. This is consistent with isoclinal folds recognized in the field. The fold axis in the small domain of the Haad Nai Phlao gneiss trend north-northwest as

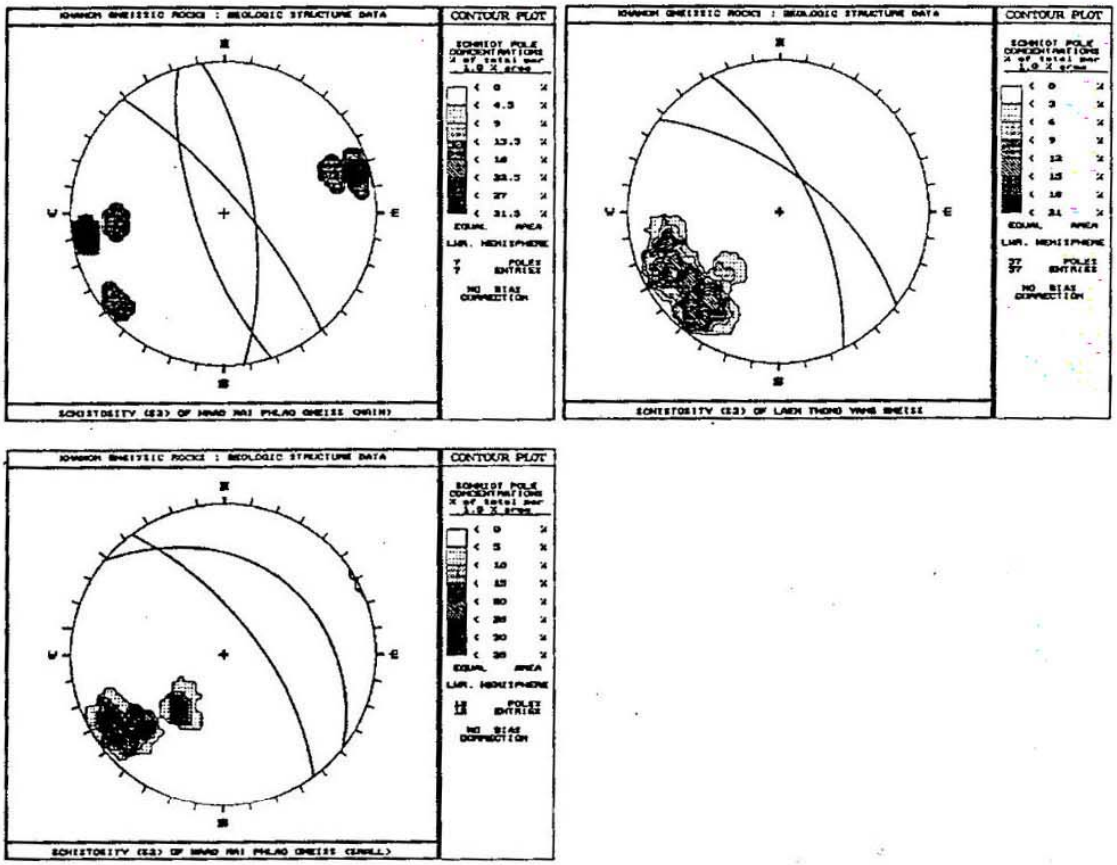

Figure 3. (continue).

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 (Fold axis = 352°/11°).

Faults

The NNE-, NNW- and E- trending fault systems represent the latest phase of deformation (S_3) can be observed throughout the area from aerial photographic and airborne radiometric maps (Charusiri et al., 1997), 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 (Figure 4) can be related to the strain ellipsoid of a Cenozoic dextral simple shear model, that is with N-S compression and E-W extension, proposed earlier by Polachan and Sattayarak, 1989 and quite disagreed with the pre-Cenozoic sinistral shear model recently proposed by Charurisi et al. (1994). Thisimplies that the left-lateral movement (S_3) may have been dominated by Cenozoic extensional tectonics.

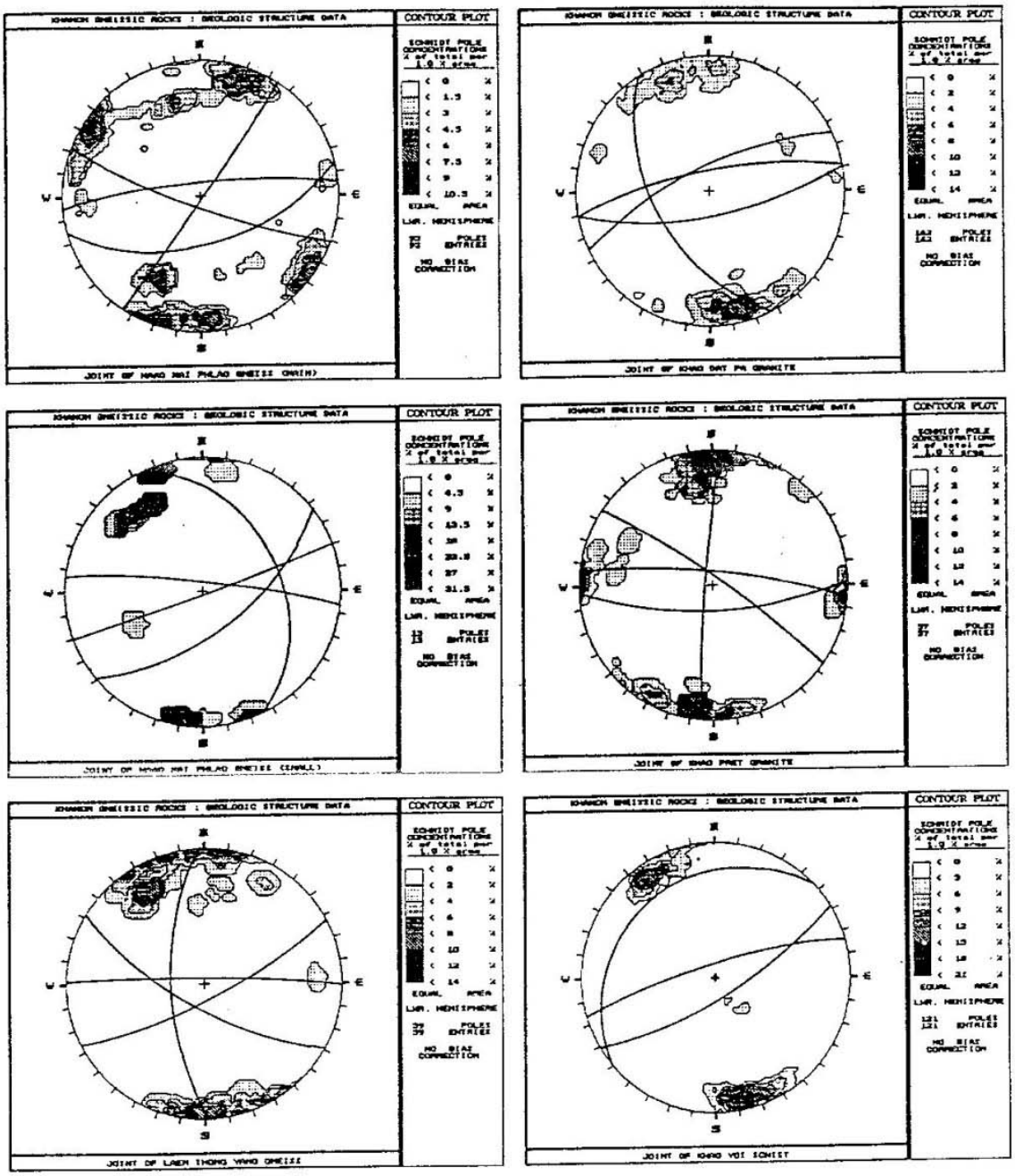

Figure 4. Contour equal area projection plots of joints of the study area.

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, almost parallel to original beddings.

From rosette diagram plots of joint planes in the study area (Figure 5), 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 (see also Table 1) can be divided into three groups in order of abundance as NNW-SSE, NNE-SSW and E-W orientations characterized by well developed

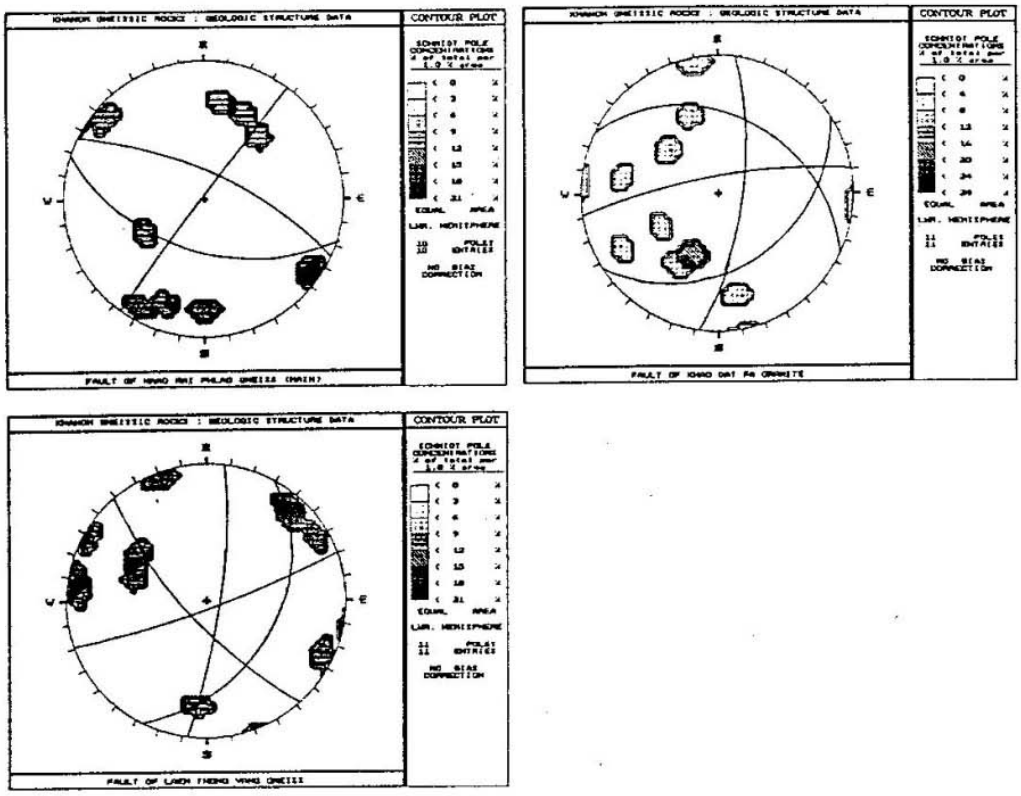

Figure 5. Contour equal area projection plots of faults of the study area.

arrangement of platy biotite. rather than the earlier compressional episode. 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.

CONCLUSION

The predominant regional foliation of the Khanom complex is north-northwesterly trending. The structural synthesis points out that at least three major phases of deformation are recognized.

Evolution of polymetamorphic gneiss of the oldest units (Haad Nai Phlao gneiss) are explained below.

Bedding (S_0) of the original sediments was folded during Precambrian (?) and a planar foliation S_1 was formed nearly parallel to the S_0 foliations during the first period of deformation and causing syn-tectonic crystallization of mica, quartz, albite, and rotational garnet, a second phase of deformation may have occurred sometimes in Triassic (?) and produced a stronger foliation S_2, with S_1 as folded relics and obliterated S_0. S_2 wrapped around albite and garnet giving pressure shadows. Mica, quartz and sillimanite are syn-tectonic metamorphic assemblage. A third minor phase, folded S_2 and faulted produced a strain slip cleavage S_3 (fault) almost parallel to S_0 and without crystal growth, possibly occurring during Tertiary (?).

It is also visualized that Cenozoic extensional tectonics with dextral shear movement is much more prominent than the pre-Cenozoic compressional tectonics with sinistral shear movement.

Table 1. Conclusion of structural attitudes of the Khanom Gneissic Complex (strike/dip).

DOMAIN	S0	S1	S2	JOINT	FAULT	Q.V.	P.V.
Haad Nai Phlao (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 (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 (3)	nr	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 (4)	nr	nr	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 (5)	nr	nr	nr	088/75 276/82 184/87 305/85	060/65	110/85	090/85
Khao Yoi (6)	nr	340/15	nr	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
nr = not reconized

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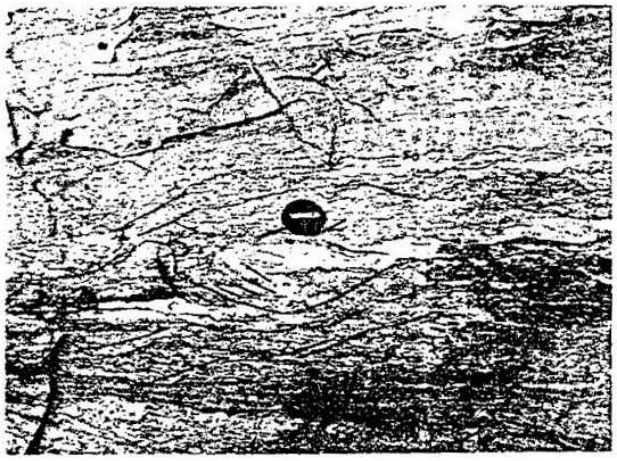

Figure 6. Interlayers of medium- and very coarse-grained gneissic texture indicate S_0 foliation of Haad Nai Phlao gneiss. Pseudobedding (S-shape white band) result from advance stage of transportation of bedding. Occasional more competent members preserve isoclinal folds, which show S_1 and S_2 foliations.

Figure 8. 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.

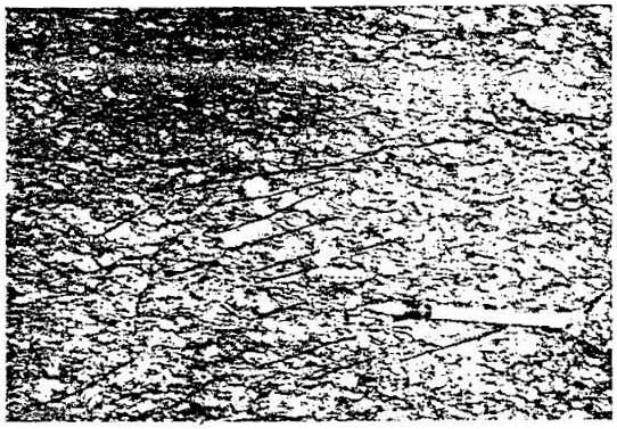

Figure 7. Shear planes (S_2) due to secondary stresses cross cut foliation (S_1)in the Laem Thong Yang gneiss with is sinistral movement near Ban Huai Sai, with S_1 = 010°/70°, S_2 = 350°/60°.

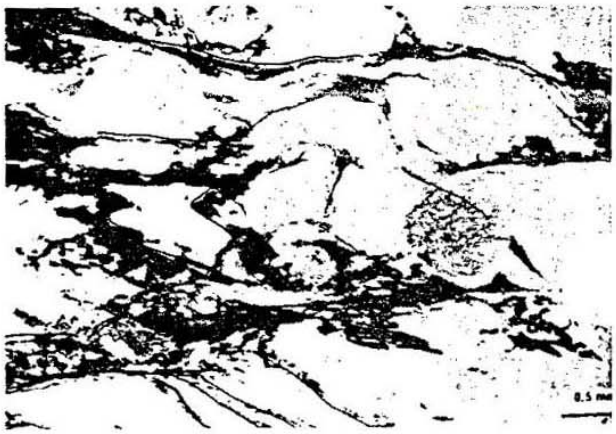

Figure 9. Photomicrograph of the Haad Nai Phlao gneiss showing isoclinal fold structure of S_1 foliation with slightly-rotated garnet, is cut by S_2 foliation as characterized by well developed arrangement of platy biotite

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