CHAPTER VIII

DISCUSSION

Accuracy of data

In this investigation, about 97.5 % of the data is accepted to determine the polarity of the individual specimens whereas less than 30-50% of them are used for calculation of the paleopole and paleolatitude. All data are regarded to be reliable since the appreciated methodology applied is standardized with rare human error, such as sample collection, sample preparation, and laboratory working. The unaccepted values of some 2.5% of data are probably due to unstable magnetism in some specimens. This 2.5% error is called error of measurement because of limited capacity of measuring the magnetism value. The unreliable and unequal values of specimens analyzed at the same site are caused by the variation of magnetism in each sample (or individual specimens), implying the presence of secular variation. The unsured data may reveal fluctuation in polarity zone or transitional zone between both polarities (Cox, 1969). It thus causes the error for determining the reliable polarity. The third error is the interval of sampling. The principal direction of magnetism, which is recognized by highest value of intensity, is not sampled. Therefore, the uncertainty of magnetism or boundary of polarity might have been effected.

Q-value - the relationship of magnetic intensity and susceptibility suggests the good recorded ancient geomagnetic field of the fine- to medium- grained sandstone (Q-value = 0.85) and fairly recorded in very fine-grained sandstone (Q-value = 0.6). Therefore, most results in this study can be proved as the corrected ancient geomagnetic field of rocks since lithification or diagenesis.

Remagnetization of Phu Thok rocks

Remagnetization in the rocks is usually found in the rocks studied. It is indicated from the occurrence of few values of secondary magnetization in most specimens (see chapters V and VI). The results of intensity plots suggest that the gradual or fluctuated decreasing in intensity (5-60% of NRM) at demagnetized temperature below 300°C (at least 90% of all specimens) and remained stable magnetization which is shown by plateau of certain magnetic intensity (from intensity plot) and direction (from zijderveld plot), occurred at the higher 300°C until the curie point. Therefore, the selected data after demagnetized process should be more than 300°C in the demagnetization . In this circumstance, all interpreted data are believed to be only the primary magnetization.

The ambient magnetic field in the present or secondary component A , 0-35% of NRM in generally E-W direction is believed as a result of reprints of the present geomagnetic field after sample collection. Nearly half of the specimens analyzed, it is not indicate the certain direction of component A. It may, therefore, add or subtract the primary magnetism. And the results obtained are from the remagnetization of present earth' s magnetic field with the primary magnetization. However, component A is not interested in the study because it is easy to demagnetize and therefore is not the case for tectonic explanation.

Goethite and protohematite (secondary component B) is also interested to discuss. In general, the red color rocks are believed to show the strongly secondary magnetization (McElhinny, 1973). However, in this study, less than 25% NRM is carried by the overprint of goethite's magnetic intensity and generally 30%NRM is defined by the protohematite's magnetic intensity. Generally, both components can be completely demagnetized at temperature above 300°-450° C and the remained intensity can be proved the ancient magnetic field of each specimen. Therefore, data of the red bed in the study should be accepted from only in the high demagnetized temperature result. The occurrence of secondary magnetism is believed to be the results of uplift (tectonics) and some weathering in the oxidizing environment of rocks in the area after rock lithification (Tarling, 1983). From the result, N-S direction of secondary component B suggests that the overprint of secondary magnetism happened after the rotation of Indochina plate (see chapter VIII). Thus, the appearance of secondary magnetism may have occurred during Tertiary (Miocene?) to Recent. This is supported by the work of Bunopas (1981) who concluded that the highest uplift of the mountainous area in the Khorat Plateau may have commenced during Miocene.

Age determination of Phu Thok rocks

Magnetostratigraphy of this area of overall studies (as Pattarametha and other, 1988 , Bunopas and other, 1989, and this study) is suggested that the paleomagnetism of Phu Thok rocks is very stable and no variable in paleomagnetic direction because the similarity of the results. Therefore, the magnetostratigraphy of the studies should be pointed to "true" magnetostratigraphy of the Phu Thok formation in the area with have reliable in proposed age.

In fact, paleomagnetic datings are generally accomplished along with the application of other age dating methods such as fossil assemblage, spore and pollen, radioactive dating or fission track (Verosub, 1985). If the only paleomagnetic dating is applied, many ages of rock will be encountered. Thus, the approximate age of Phu Thok rocks in the area has to be determined incombination with the other relevant geological and geophysic informations and interpretations.

1. Geophysic & Geologic informations

From the previous studies (e.g. Sattayarak, 1983), the Phu Thok formation in the study area was assigned to the uppermost part of Khorat sequence, therefore the end of sediment deposits of Khorat marks the minimum age of the Phu Thok deposit. The complete deposition of all formations of the Khorat Group occurred during Middle to Late Cretaceous Periods (Bunopas, 1981 and Maranate, 1982). However, the work of Mouret and others (1993) suggested that the uplift of consolidated sedimentary Khorat rocks was first started at 65 Ma and mostly the Khorat Group rocks are completely deposited during the Early Paleocene. They found the different rate of erosion of post-Mesozoic and Mesozoic rocks. Mouret and others 's hypothesis is similar to that proposed earlier by Sattayarak and Polachan (1990). The paleomagnetism record of McCabe and others (1993) suggested that the evidence of tectonism (such as rotation) for the Indochina massif took place at least after Late Miocene. The rocks in the Khorat Plateau which are younger than Late Miocene such as basaltic rocks, show the northward paleodecination, whereas the older than Late Miocene such as Cretaceous clastic rocks reveals the northeastward paleodeclination (Van der Voo, 1993). The paleomagnetic declination of Phu Thok in the area is likely to conform with the latter. Furthermore, Funahara and others (1992) stated that the clockwise rotation of the Cretaceous rocks in Chuxiong area of the southern China block occurred as a result of the strike-slip Red River Fault during Early Paleogene. Enkin and others (1992) predicted that the left lateral strike slip Red River Fault may have rotated the Khorat Plateau since post Cretaceous. From both studies, it is inferred that the rotation was acted in the rocks older than Cenozoic. The Phu Thok is certainly characterized by rotation about 30° -40° from the stable Erasia, but the younger rocks in the Khorat Plateau are not shown. These reasonable data advocate that the Phu Thok formation at Khao Phu Thok and Phu Wua should be older than Cenozoic.

The attitude of Phu Thok formation at Phu Thok and Phu Wua is denoted by subhorizontal dipping and its extension to Laos may be limited by the appearance of the Phra Wihan, the Sao Khua and the Phu Phan Formations (Sattayarak and Polachan, 1990). Therefore, at least the age of Phu Thok is presumably younger than that of the Phu Phan Formation which was deposited since Late Jurassic to Early Cretaceous (Bunopas, 1992) or early-middle Early Cretaceous (Mouret, 1994, Jirin and Morley, 1994 and Racey and others, 1994). From the result of previous studies, it is quite likely that in terms of geological and tectonic scenario, the deposition of the

Phu Thok rocks in the study area is rather limited from Late Jurassic to Cretaceous periods.

This proposed age is the based data for interpretation the Phu Thok age by magnetostratigraphy because the long normal with short reverse bands in the top and long reverse in the bottom sequence is fit with many time of standard ranging from Tertiary to Jurassic. In this discussion, Tertiary and Early to Middle Jurassic are rejected, therefore, the estimated age of the Phu Thok rocks is easier to correlated.

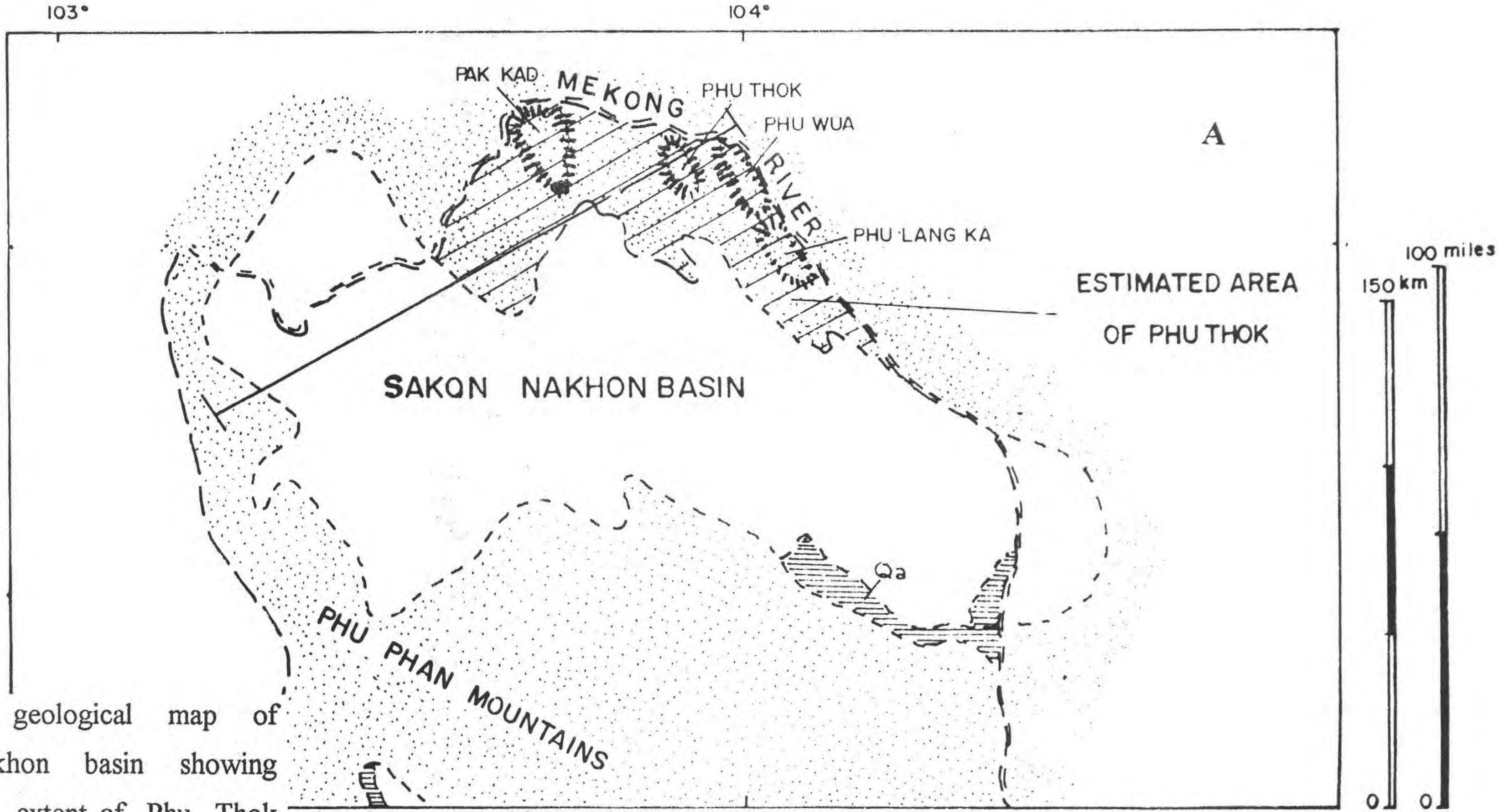
2. Geologic interpretation

The older than Maha Sarakam Formation (Middle Cretaceous) of Phu Thok rocks in the area can also be answered by geologic evidence. The overlied Phu Thok on Maha Sarakam Formation is accepted by Sattayarak and Polachan (1990). Their belief is based primarily upon the occurrence of thick red sandstone beds on the Maha Sarakam Formation at several drilling holes. The thick red sandstone (>200 m or up to 800 m of Ratanajaruraks, 1990) was therefore correlated with the Phu Thok reference section (in the area). This idea was not accepted by several geologists as Piyasin (1985 and 1995) and Imsamut and others (1994), who strongly believed that those thick red sandstone strata are not similar to those of the "Phu Thok exposed reference section (in the study area)" and that the rock salt sequence is underlain by the Phu Thok rocks which occur as mountainous areas.

At the reference section, the Phu Thok formation at the mountainous area is unconformably correlated with the mudstone-clastic unit by fault contact. However, data of ground water drilling wells (Groundwater Division, 1978) at Changwat Nong Khai suggest that the extension of Phu Thok rocks not be limited at the mountainous area as Phu Thok, Phu Sing, Phu Wua and Phu Langka. These rocks still occur in some areas which are mapped as Maha Sarakam Formation. In the underground surface between Amphoe Bung Kan and Pon Phi Sai, the Formation is recognizable to be overlain by thin sequences of clastic rocks of the mudstone- clastic unit (or Maha be overlain by thin sequences of clastic rocks of the mudstone- clastic unit (or Maha Sarakam Formation?) at depth between 5 and 30 m. The mudstone-clastic unit or Maha Sarakam sequence near the west of Amphoe Pak Kad therefore displays a continuously gradual increasing in thickness from mountainous to undulating areas at between 1 and 30 m overlied the Phu Thok rock sequence at the west of the area. The extension of the Phu Thok rocks sequence may have been laterally extended at least 50 km westward and eastward (Fig. 8.1). From the stratigraphic sequence, it is assumed that the age of Phu Thok rocks may be older than the rock salt.

The investigation which supported this idea is the structural synthesis performed by Piyasin (1995). The Phu Thok formation at Amphoe Pak Kad is believed to be at the edge of the Khorat Plateau which separates the Vientiane and the Sakon Nakhon subbasins (Fig. 8.2). It can be supported also by landsat interpretation (Supajanya, per com.). The geology of Laos near the Mae Nam Khong comprise also the upper unit of the Khorat Group (see Fig 2.2). Their regional structural trend is conformed to the river. The sequences are believed to occur at the edge of Sakon Nakhon basin (see Piyasin, 1995). The Phu Thok (in the area) structural feature is, therefore, likely to follow these rocks and apt to become the upper sequence parallel to the structural feature of the Khok Kruat (or Ban Na Yo Formations) and plunging to the south beneath the Mara Sarakam Formation. Therefore, it is possibly identified that the Phu Thok sequence is likely the uppermost unit, basement of Maha Sarakam Formation.

Previous work by Sattayarak and Polachan (1990) shows subsurface cross-section of the Phu Thok formation (informal name) of the Khorat and the Sakon Nakhon basins (Fig 8.3). This cross-section elucidates correlation of the Phu Thok at the type section with these rocks in the central basin as the equivalent unit. The argument of their idea is that the Phu Thok red sandstone at the exposed section is quite thick (>200 m) and is nearly the same as that of the central basin. In term of sedimentology, the deposition in the central basin is usually more than that of the edge of the basin during the mild tectonic episode. However, regional geology of the study



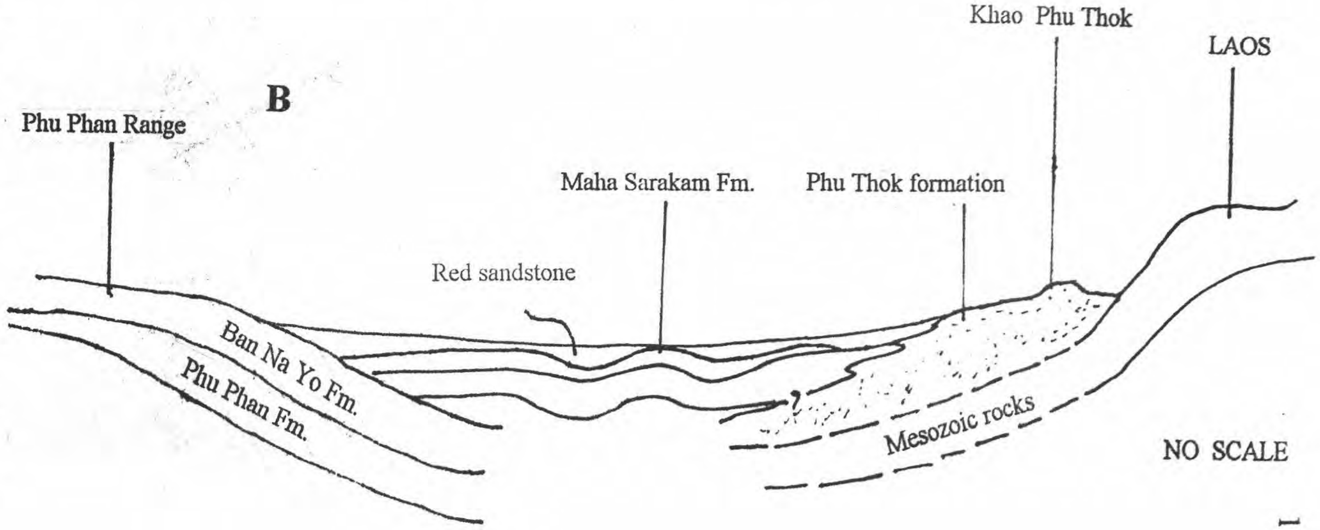


Figure 8.1 Simplified geological map of Sakon Nakhon basin showing the aerial extent of Phu Thok formation which may have undercovered by Maha Sarakam Formation to the depth of 30 m (A) and ideal geologic cross - section of this study (B). (subsurface data is received from DMR and boundary of estimated Phu Thok formation and the rock salt is based on Rau and Supajanya (1985).

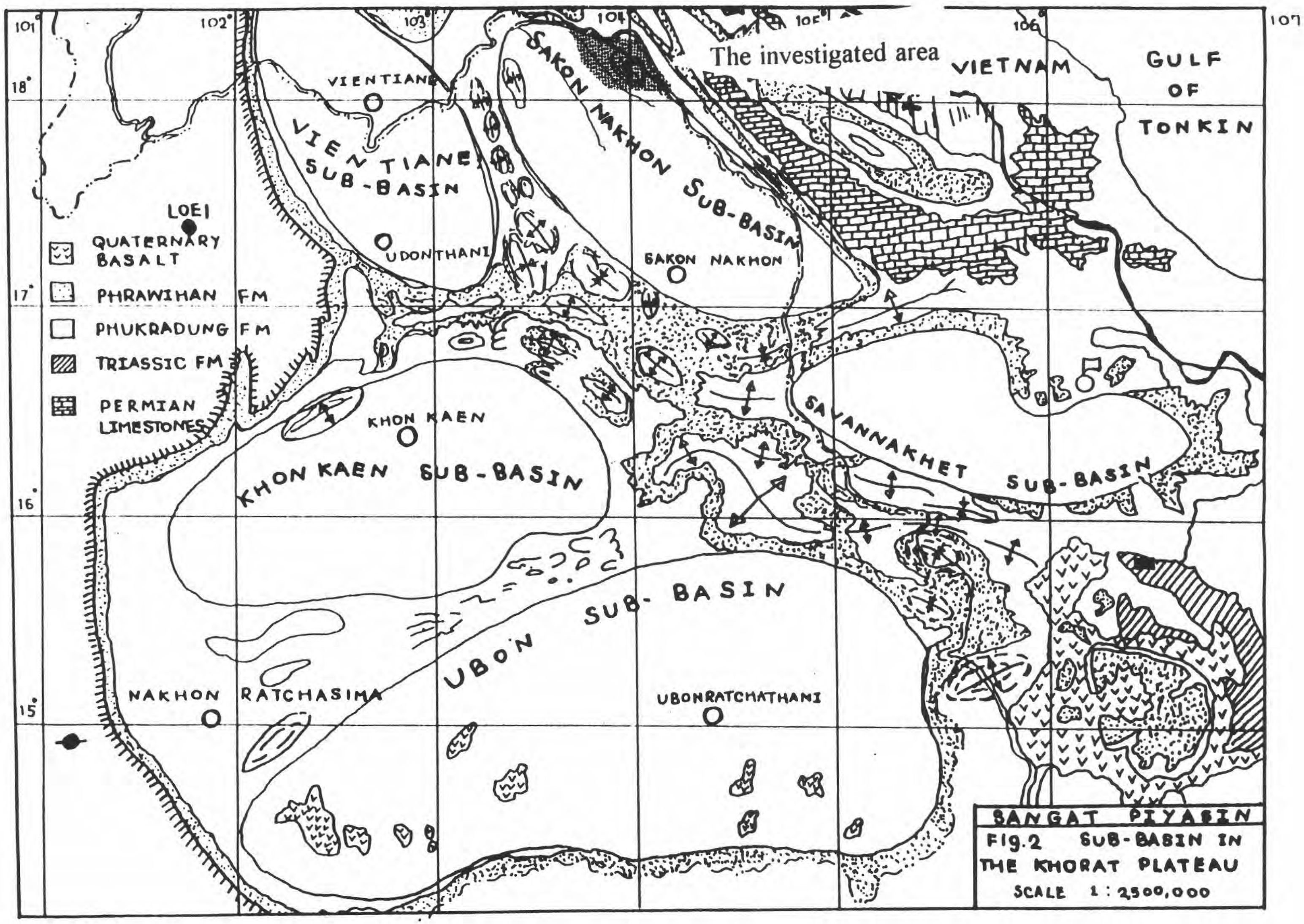


Figure 8.2 Ideal geologic map in the northeastern Thailand by Piyasin (1995)

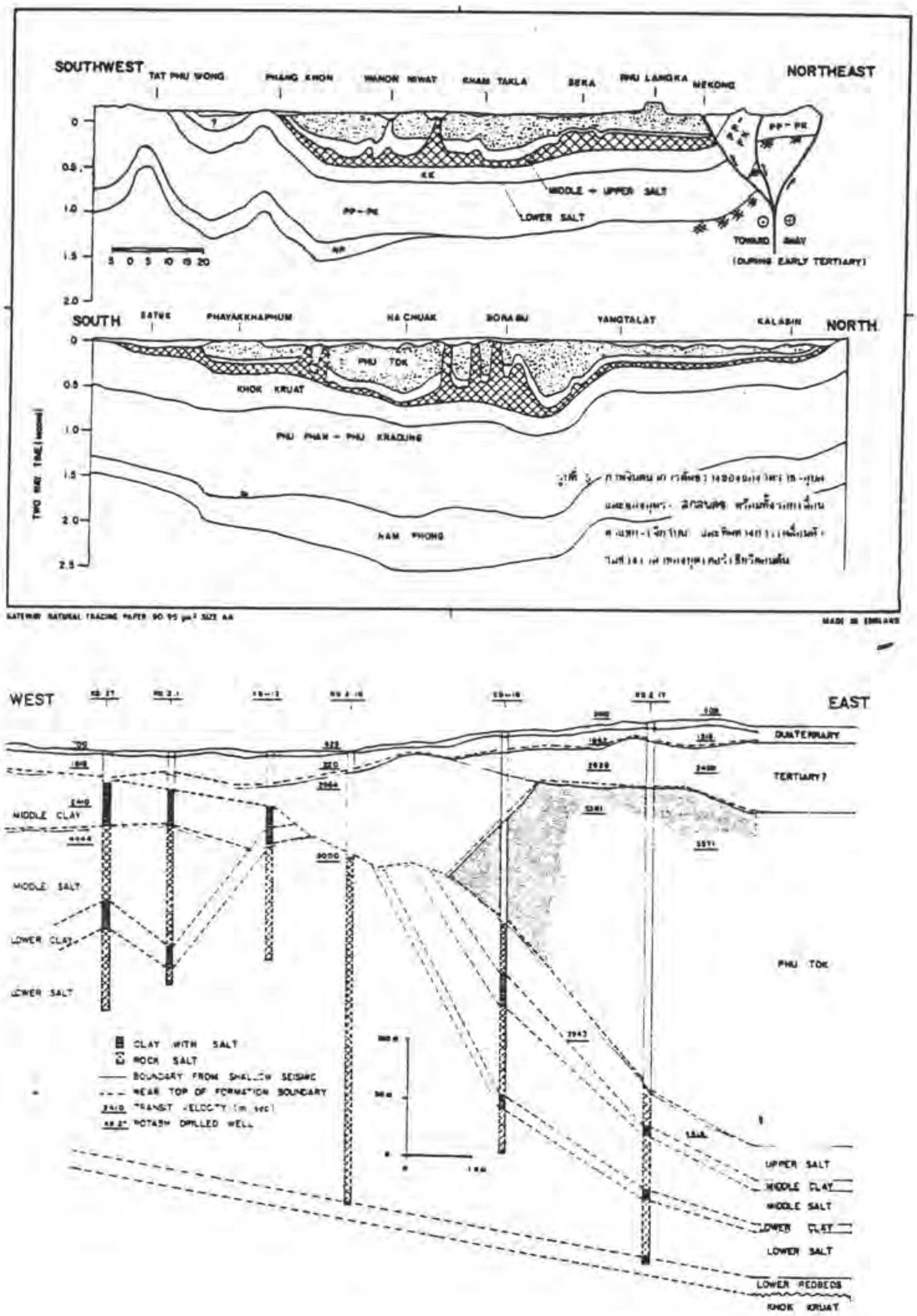


Figure 8.3 Ideal geologic cross-section of the Phu Thok Formation by Sattayarak and Polachan (1990).

Nakhon basin. It is therefore unclear if the very thick sequence (-in their idea, the red sandstone deposited after the Maha Sarakam Formation) of the Phu Thok type section occurring in the area. In the Sattayarak and Polachan' s (1990) paper, the reverse fault is introduced along Mae Name khong River (or the so-called strike-slip Takhek Fault, of Mouret, 1994, parallel to the Red River fault) and the Upper Khorat in Laos is suggested to be uplifted (at about 3,000 m, by the author) on the surface and the younger rocks were subsequently almostly eroded. The age of this fault is inferred to be Early Tertiary (Sattayarak, op.cit.). The controversy of their hypothesis is the existence of this fault and if exist, there is no evidence of salt dome along the fault, if the Phu Thok rocks are younger.

The appearance of fault may have been possible (see Figs. 1.1 and 2.2) since the area is one of the seismic focus in Laos near the Mae Nam Khong. In the Russian geological map of mainland SE Asia (Gatinsky, 1973), boundary of the Upper Mesozoic (refer to Phu Phan-Phra Wihan) in Laos is unconformity marked by the fault contact with the Middle Mesozoic (refer to Phu Kradung) without intense uplift. If Sattayarak and Polachan's idea is true, the Sakon Nakhon basin should have been larger than this, and Phu Thok should have been situated in the central part of the basin (see also Fig. 7.7). Then the Maha Sarakam and the rocks in the area which may have been extended to Laos (or possibly to Veitnam) were completely eroded at the hanging wall of the fault (in Laos). However, as shown in Fig. 2.1, it is likely that the Phu Thok clearly extended to Laos and may have been exposed. Therefore, the presence of the reverse fault is unclear.

The evidence of salt dome at the present usually occurs in the E-W to ESE-WSW directions at the central part of the Khorat and the Sakon Nakhon basins. If the Sattayarak and Polachan' idea is correct, the salt domes under the Phu Thok sequence at/or near the study area should be exposed along these major fractures, especially near the Mekong River because of the compression of fault. But in the Phu Thok and Phu Wua areas , the evidences of salt dome are not detected but most of the rock salts usually occur in the areas mainly bounded by Phu Thok and the other

Mesozoic formations (see Figs. 2.2 and 8.2). Therefore, the underlain Phu Thok Formation in the area by the rock salts are more doubtful than the case of it overlying the Phu Thok rocks in the area as the Maha Sarakam Formation (which mostly eroded) (Fig 8.1). Therefore the Phu Thok in the area should be older than Middle Cretaceous. The uppermost is the thick sequence of sandstone of the Borabu formation (Piyasin, 1985) which is not equivalent to the Phu Thok Formation "sensu stricto".

The discussion indicate that Phu Thok formation in the area should be older than Maha Sarakam Formation or older than Middle Cretaceous, therefore, the estimated age of the Late Cretaceous (by magnetostratigraphy are resigned. The Early Cretaceous (or to Late Jurassic) from magnetostratigraphy is fit with the evidence of tectonic before the deposition of Mara Sarakam was occurred. Thus, the proposed age of this study should be accepted.

Comparison paleomagnetic results of the Phu Thok with the other plate

The results of the paleomagnetic pole for each member of the individual sections (see Table 6.3) indicate the very stable paleopole since the sediment deposits in the Phu Thok basin took place. It may have occurred close to the quiet long normal polarity of Cretaceous rocks. However, the difference in paleomagnetic poles of the lowest part of the Phu Thok sequence in the area probably implied some variation in reverse polarity alternated in the dominant normal polarity. This perhaps gives rise to some uncertainty of the average paleomagnetic pole.

Since the stable paleomagnetic pole is recognized in the rocks, the mean of paleomagnetic pole is referred to Grand Mean Pole (GMP) of the Phu Thok Formation. It is 61.9° N, 189.9° E (with K= 1006.0, A_{95} =1.8, dP=1.2 and dM=2.0), which indicates a very good result. The paleolatitude of the study area depends largely on the resultant paleopole. This paleolatitude of the Phu Thok is also quite stable. Average paleolatitude of the Formation is 17.8° ± 1.2° N (with A_{95} =1.8), implying that it is nearly located at the same latitude of the present site. However, paleolongitude cannot be calculated from the paleomagnetic data.

The declination of the rocks in the area shows the very surprising result. Most samples, up to 85%, reveal the N- to NE- direction. The range of declination appeared in the selected Phu Thok samples is from 356.6° to 70.5° and the average is 29.6°. It is inferred that clockwise difference of the rocks in Khao Phu Thok and Phu Wua mean declination certainly occurs neither as a result of Recent - Late Cenozoic tectonics nor weathering of the Phu Thok formation. The large proportion of the sites seem to have good demagnetization characteristics and a good agreement to the directions of magnetization. Furthermore, the secondary magnetization affected by ambient field in Recent age or post-lithification of the Phu Thok deposit, show the N-trending direction at the low demagnetized temperature steps, and are converted to the NE-trending direction at the high appreciated temperature steps (see Chapter VI). Therefore, the rotation which was preserved in the rocks occur mainly from the primary characteristic in the sedimentary basin.

Previously reported paleomagnetic pole positions of Indochina rocks in Thailand are concluded in Table 8.1, and previous reports of paleomagnetic data of Middle -Upper Mesozoic, especially Cretaceous of the adjacent plates, are illustrated in Table 8.2. The APWP (or Apparent Polar Wander Pole) of the stable land of this South-east Asia with respect to Eurasia during Mesozoic proposed by Enkin and others (1992), is shown in Table 8.3. The APWP of each plate at the time of Cretaceous to Jurassic Periods are elucidated in Table 8.4 and the records of paleolatitudes of the individual plates since Middle Mesozoic are displayed in Table 8.5. The expected poles of Indochina, Shan-Thai, South China and Eurasia during Mesozoic Era are recorded in Fig. 8.4.

1. Comparison with Indochina plate (or eastern Shan-Thai/Indochina microcontinent)

If the magnetostratigraphy of the rocks in Khao Phu Thok and Phu Wua defines the Early Cretaceous age (in Chapter VII), the GMP (Grand Mean Pole or average VGP) can then be correlated with the nearly Cretaceous rocks of Indochina continental plate (Table 8.1). This Phu Thok and Phu Wua paleopole, 61.9° N, 189.9° E (with K= 1006.0, A_{95} = 1.8, dP = 1.2 and dM = 2.0) conforms with the VGP of Early Jurassic to Early Cretaceous rocks (refer to Nam Phong - Phu Phan Formation) reported by Yang (1992). The Phu Thok and Phu Wua paleopole can be also correlated with the paleopoles of Phra Wihan, Sao Khua and Phu Kradung Formations (Early-Late Jurassic) of Barr and Macdonald (1978), Bunopas (1981), Maranate (1982) and Chen and Courtillot (1989). However, except for the study of Yang (op. cit.), the paleomagnetic data of Lower Cretaceous obtained from the Indochina rocks can not be matched with the result of this study (see Table 8.1). For instance, pole of Cretaceous rocks reported by of Bunopas (1981) is based solely on too small measurements, and indicated higher paleopole-latitude exceeding 19° with quite high A_{95} , up to 43, whereas the result of Cretaceous rocks of Maranate (op. cit.) is lower than that of this current study. It is also mentioned that these two other Cretaceous sites yield questionable results, particularly the declination. Furthermore, their Cretaceous data are not related to those of the older rocks (Yang, op. cit.). However, if their Cretaceous data are correct, it might have been suggested that most rotation of the Jurassic declinations resulted from tectonic rotation of northeast Thailand (Indochina) prior to Cretaceous (Maranate, 1982). With the better and higher technology of paleomagnetic work by Yang (op.cit.), it is quite likely and more reasonably that the GMP of Phu Thok samples of the study area seem to fit very well with the Early Cretaceous Phu Phan Formation of the same Indochina plate.

The paleolatitude of Indochina rocks as proposed earlier by Maranate (1982) and Van der Voo (1993) (Table 8.5) suggested the slightly fluctuated movement of the Khorat Plateau since Upper Triassic to Recent. The highest paleolatitude with respective to the present continent as recorded by Achache and Courtillot (1985), is up to +9° positive latitude different from present. Maranate (op.

Table 8.1 List of Paleomagnetic Poles of rocks in the Indochina continent

Formation	Age	Number(n)	Ds	Is	K	A_{95}	Pole lat.	Pole long.	dP	dM	References
Basalt , east of Thailand	Q-Tu	53(?)	4.0	-	15	5	86.0	171.0	-	-	McCabe et al. 1988
Khok Kruat	K	2(6)	10.0	34.0	36	43	79.0	176.0	28	49	Bunopas, 1981
Khok Kruat	K	7(21)	47.0	29.0	19	14	45.0	189.0	9	16	Maranate, 1982
Phu Phan	Kl	3(9)	45.0	19.0	10	41	46.0	197.0	23	43	Maranate, 1982
Phu Phan	Kl(B)	88(?)	28.1	40.5	391	2.4	62.7	173.7	-	-	Yang, 1992
Phu Phan	Kl(C)	77(?)	32.0	38.2	114	4.5	59.4	177.4	-	-	Yang, 1992
Sao Khua	Ju	16(48)	33.0	35.0	23	8	59.0	184.0	5	9	Maranate, 1982
Sao Khua-Phra Wihan	Ju-Jm	36(?)	26.6	37.3	443	2.3	64.0	178.1	-	-	Yang, 1992
?	Ju-Jm	14(36)	29.0	46.0	10	14	67.0	177.0	11	17	Bunopas, 1981
?	Ju-Jm	9(?)	2.0	23.0	133	76	80.0	111.0	43	81	Barr & Macdonald, 1978
?	J	-	25.4	35.8	25	8	59.0	175.0	-	-	Chen Yan & Courtillot, 1989
Phra Wihan	Jm	14(42)	31.0	41.0	10	13	60.0	174.0	10	16	Maranate, 1982
Phu Kradung	Jl	15(45)	38.0	29.0	21	7	58.0	188.0	4	8	Maranate, 1982
Phu Kradung-Nam Phong	Jl	61(?)	37.2	40.1	18	7.3	54.4	175.6	-	-	Yang, 1992
?	Jm-Jl	10(?)	36.0	39.0	32	12	56.0	176.0	9	14	Barr & Macdonald, 1978
?	Jm-Jl	19(?)	26.0	36.0	15	15	64.0	171.0	10	17	Barr & Macdonald, 1978
Nam Phong	Jl-Tru	9(27)	34.0	41.0	20	12	58.0	174.0	9	14	Maranate, 1982
Huai Hin Lat	Tru	58(?)	39.5	44.4	109	7.3	52.1	169.8	-	-	Yang, 1992
Huai Hin Lat	Tru	?	44.0	-	106	8	49.0	172.0	-	-	Achache & Courtillot, 1985
Huai Hin Lat ?	Tru	8(24)	30.0	20.0	11	18	60.0	135.0	10	19	Bunopas, 1981
Lom Sak	Tru	10(30)	18.0	21.0	13	14	71.0	208.0	8	15	Maranate, 1982
Mean of Khorat (exclude. Lom Sak)	Kl-Jl	64(192)	37.0	32.0	63	9	54.0	186.0	5	10	Maranate, 1982
Phu Thok (exclude. lowest Phu Wua)	K	236(361)*	29.6	35.7	1006	1.8	61.8	189.9	1.2	2	In this study

Remark : Q=Quaternary, Tu = Upper Tertiary, K = Cretaceous, Kl= Lower Cretaceous, Ju = Upper Jurassic, Jm =Middle Jurassic , Jl= Lower Jurassic , Tru = Upper Triassic , Number (n) = accepted number of data (total data), Ds = corrected declination, Is =corrected inclination, Pole lat. = VGP latitude, Pole long. = VGP longitude, K= precision parameter, A_{95}= cone of confidence, dP=error in pole-latitude dM=error in direction perpendicular to the dP , and * = number of specimens

Table 8.2 List of Paleomagnetic Poles of rocks in Shan-Thai and South China

Formation	Age	Number(n)	Ds	Is	K	A_{95}	Pole lat.	Pole long.	dp	dM	References
Shan-Thai (Recent-Upper Triassic)											
Volcanic in Burma	Q	?	5.5	-	-	-	-	-	-	-	Richter &Fuller, undate
Toba tuff, west Sumatra	Q	?	5.0	-	28	5	85.0	183.0	-	-	Yokoyama & Dharma, 1982
Khantan Lava, Malaysia	Q	?	353.0	-	6	54	79.0	317.0	-	-	Haile et al., 1983
Late Cenozoic, Thailand	Q	?	10.0	33.9	-	-	80.0	186.5	-	-	Bunopas, 1981
Volcanic, west Malasia	Tm	?	35.0	-	-	12	56.0	190.0	-	-	Haile, 1979
Volcanic&sediment, Sumatra	Q-Tl	?	4.0	-	20	10	84.0	130.0	-	-	Sasajima et al., 1978
Diorite , west Sumatra	Tu-Tl	?	8.0	-	-	6	82.0	183.0	-	-	Haile, 1979
Chindwin basin, Burma	Tl	?	20.0	-	-	-	-	-	-	-	Richter &Fuller, undate
Basalt & Dike, Malaysia	Ku-Km	?	311.0	-	16	9.0	44.0	35.0	-	-	McElhinny et al., 1974
Surat Thani, south Thailand	Ju-Jm	1(3)	29.7	42.9	-	13.6	61.0	170.0	-	-	Bunopas, 1981
North Thailand	Ju-Jm	4(?)	33.0	28.2	74.6	75.6	58.2	188.0	46	83	Bunopas, 1981
North Thailand	Jl	?(12)	65.9	35.8	3.1	62.9	28.0	177.6	42	73	Bunopas, 1981
Mesozoic rocks at Sagaing fault	K-J	?	40.0	-	-	-	-	-	-	-	Richter &Fuller, undate
South China (Jurassic-Cretaceous)											
Red bed, Kwangtung Prov.	Km	?	30.0	56.0	-	4	61.0	170.0	4	6	McElhinny, 1969
Red bed, Kwangtung Prov.	K	?	21.0	60.0	-	6	54.0	141.0	7	9	McElhinny, 1969
Red bed Yunnan Prov.	K	?	33.0	45.0	-	18.0	60.0	186.0	14	23	McElhinny, 1969
Red bed Canton Prov.	K	?	33.0	55.0	-	-	54.0	162.0	-	-	McElhinny, 1969
Chuxiong, west Yunnan	K	129(?)	44.6	41.3	9.8	10.7	49.2	178.0	-	-	Enkin, 1990
Eastern part of the Yangtze block	K	5*	19.1	38.3	-	7.2	77.0	200.0	-	-	Chen, 1991
Western Sichuan	K	3*	0.3	26.2	-	5.1	78.8	280.0	-	-	Otufuji et al., 1990
Qiangtan Terrane	K	3*	46.7	49.7	-	12.6	48.6	172.9	-	-	Otufuji et al., 1990
Ya'an, Sichuan	K	44(79)	2.1	30.7	21.7	11.3	76.3	85.5	-	-	Otufuji et al., 1990
Lhasa Terrane	K	25(43)	3.3	29.0	11.7	28.0	71.8	70.8	-	-	Otufuji et al.,1990
Motoushan Formation, Chuxiong area	Ku	57(?)	45.6	46.6	12.4	14.3	-	-	-	-	Funahara et al., 1992
Fexianguan area	Ku	?(189)	15.0	30.8	38.0	6.1	70.8	234.0	3.8	6.8	Enkin, 1990
Puchanghe Formation, Chuxiong area	Kl	72(?)	43.7	36.2	8.1	10.7	-	-	-	-	Enkin, 1990
Xinjin area	Kl	?(305)	28.0	36.4	56.7	4.1	71.0	219.8	2.8	4.8	Enkin, 1990
Red bed , South China	Ku	23*	-	-	-	3.2	74.5	229.0	-	-	Enkin et al., 1991

Formation	Age	Number(n)	Ds	Is	K	A_{95}	Pole lat.	Pole long.	dp	dM	References
South China (continue)											
Red bed , South China	Ku	9*	-	-	-	11.1	76.3	265.5	-	-	Otofuji et al., 1990
Red bed , South China	Ku	?	-	-	-	15.0	77.4	196.2	-	-	Zhu et al, 1988
Red bed , South China	Kl	10*	-	-	-	10.3	76.3	172.6	-	-	Kent et al, 1986
Granite, South China	Kl	12*	-	-	-	10.6	78.2	171.9	-	-	Chen, 1991
Red bed, South China	Kl	3*	-	-	-	5.5	78.9	186.6	-	-	Zhu et al., 1988
Guanyin	Ju	?(62)	17.4	34.8	33.3	19.2	70.9	223.5	8.9	15.5	Enkin, 1990
Red bed Yunnan Prov.	J	?	21.0	64.0	-	33	64.0	139.0	43	53	McElhinny, 1969
Red bed Sichuan Prov.	J	?	45.0	64.0	-	31	51.0	157.0	40	50	McElhinny, 1969
Phu Thok	K	236(361)**	29.6	35.7	1006	1.8	61.8	189.9	1.2	2	In this study

Remark : Q=Quaternary, Tu = Upper Tertiary, Tm =Middle Tertiary, Tl = Lower Tertiary, K = Cretaceous, Kl= Lower Cretaceous, Ku= Upper Cretaceous, Km = Middle Cretaceous, Ju = Upper Jurassic, Jm= Middle Jurassic , Jl= Lower Jurassic , Number (n)=accepted number of data (total data), Ds = corrected declination, Is = corrected inclination, Pole lat. = VGP latitude, Pole long. = VGP longitude, K= precision parameter, polelatitude A_{95} = cone of confidence, dP=error in pole-latitude, dM=error in direction perpendicular to the dP , and * = number of sites

Table 8.3 List of APWP of Mesozoic rocks in Eurasia

Formation	Age	Pole lat.	Pole long.	K	A95	dP	dM	References
Cretaceous	80 Ma	77.0	199.0	-	3.0	-	-	Enkin et al., 1992
Upper Jurassic	140 Ma	70.0	158.0	-	7.0	-	-	Enkin et al., 1992
Middle Jurassic	175 Ma	63.0	129.0	-	3.0	-	-	Enkin et al., 1992
Lower Jurassic	200 Ma	67.0	109.0	-	4.0	-	-	Enkin et al., 1992
Upper-Middle Triassic	225 Ma	56.0	130.0	-	10.0	-	-	Enkin et al., 1992
Phu Thok	110 Ma	61.8	189.9	1006	1.8	1.2	2.0	in This study

Table 8.4 List of APWP of Mesozoic rocks in each terrain

Formation	Age	Pole lat.	Pole long.	K	A_{95}	dP	dM	References
Indochina block								
Khok Kruat	80 Ma	45.0	189.0	-	-	9	16	Maranate and Vella, 1986
Upper Khorat Gr.	80-140 Ma	63.8	175.6	377.9	1.7	-	-	Yang, 1992
Khorat Group	140-200 Ma	54.0	186.0	63.0	9.0	5	10	Maranate, 1982
Lower Khorat Gr.	175-200 Ma	54.4	175.6	18.0	7.3	-	-	Yang, 1992
Huai Hin Lat	225 Ma	49.0	172.0	-	7.0	-	-	Achache & Courtillot,1985
Shan Thai block								
South Thailand	140-175 Ma	61.0	170.0	-	13.6	-	-	Bunopas, 1981
North Thailand*	140-175 Ma	58.2	188.0	74.6	75.6	46.0	83.0	Bunopas, 1981
South China								
Mean South China	65-98 Ma	77.9	203.8	-	14.2	-	-	Enkin et al., 1992
Mean South China	65-98 Ma	77.0	220.6	-	6.1	-	-	Yang, 1992
Nanjing	65-98 Ma	76.0	173.0	42.0	8.0	-	-	Kent et al., 1986
Ya'an, Sichuan	65-144 Ma	76.0	275.0	22.0	11.0	-	-	Otufuji et al., 1990
Jiangsu, Hubei	65-144 Ma	73.0	180.0	38.0	7.0	-	-	Kent et al., 1987
Tuff& redbed, Xinchang	98-144 Ma	77.0	228.0	120.0	6.0	-	-	Van der Voo, 1993
Mean South China	98-130 Ma	75.6	175.0	-	6.7	-	-	Yang, 1992
Mean South China	98-130 Ma	77.8	208.4	-	7.0	-	-	Enkin et al., 1992
Mean South China	140 Ma	72.3	208.6	-	13.5	-	-	Enkin et al., 1992
Mean South China	175 Ma	65.0	186.2	-	15.0	-	-	Enkin et al., 1992
Mean South China	200 Ma	69.4	192.4	-	7.4	-	-	Enkin et al., 1992
Mean South China	225 Ma	45.1	194.4	-	16.8	-	-	Enkin et al., 1992
Phu Thok	108-118 Ma	61.8	189.9	1006	1.8	1.2	2	In this study

Table 8.5 List of paleolatitude of Middle -Late Mesozoic rocks in each terrain

Formation	Age	Pres. lat. (°N)	Mean I (°)	Paleo lat. (°N)	Lat.Diff. (°)	References
Indochina block						
Basalt east Thailand	Q-Tu	14.0	-	20-21	approx.6-7	McCabe et al. , 1988
Upper Khok Kruat	K	17.3	38.0	21.3	-4.0	Maranate, 1982
Khok Kruat	K	17.3	29.0	15.5	1.8	Maranate, 1982
Phu Phan	Kl	17.3	19.0	9.8	7.5	Maranate, 1982
Phu Phan	Kl	16.8	39.3	22.3	-5.5	Yang, 1992
Sao Khua	Ju	17.0	35.0	19.3	-2.3	Maranate, 1982
Phra Wihan	Jm	16.5	41.0	23.5	-6.8	Maranate, 1982
Sao Khua-Phra Wihan	Ju-Jm	16.8	37.3	20.9	-4.1	Yang, 1992
?	Ju-Jm	16.0	46.0	27.4	-11.4*	Bunopas, 1981
?	J	16.0	35.8	19.8	-3.8	Chan & Courtillot, 1989
?	Jm-Jl	17.0	38.5	21.1	-4.1	Barr & Macdonald, 1978
Phu Kradung	Jl	17.0	31.0	16.7	0.3	Maranate, 1982
Nam Phong	Jl-Tru	17.0	41.0	23.5	-6.5	Maranate, 1982
Lomsak	Tru	17.0	21.0	10.9	6.1	Maranate, 1982
Huai Hin Lat	Tru	17.0	-	26.0	-9.0	Achache * Courtillot,1985
Average Khorat	K-Jl				-0.49	Maranate, 1982
Mean Khorat	Kl/Ju	16.8	-	23.6	-6.80	Yang, 1992
Shan Thai						
Red bed, south Thai.	Ju-Jm	9.0	42.9	24.4	-15.4*	Bunopas, 1981
Red bed north Thai.	Ju-Jm	19.0	28.2	15.0	4.0	Bunopas, 1981
Red bed north Thai.	Jl	19.0	35.8	19.8	-0.8	Bunopas, 1981
South China						
Matoushan , w.Yunnan	Ku	25.0	46.6	27.9	-2.9	Funahara et al.,1992
Kwangtung	K	23.3	56.0	36.5	-13.2*	Maranate, 1982
Yunnan (Rotate)	K	25.0	45.0	26.5	-1.5	Maranate, 1982
Ya'an, Sichuan	K	30.1	30.7	16.5	13.6	Otufuji et al., 1990
Qiangtang terrane(Rotate	K	29.7	49.0	29.9	-0.2	Otufuji et al., 1990
Lhasa terrane	K	30.1	23.4	12.2	17.9	Otufuji et al., 1990
West Sichuan	K	26.5	37.7	21.1	5.4	Kent et al, 1986
Puchanghe, w.Yunnan	Kl	25.0	36.2	20.1	4.9	Funahara et al., 1992
South China mean	Kl-Ju	26.0	-	18.9	7.1	Yang, 1992
Saping, Sichuan	Kl-Ju	29.9	35.7	19.8	10.1	Enkin, 1990
Changshou, Sichuan	Jm-Jl	29.7	46.5	27.8	1.9	Enkin, 1990
Yunnan	J	25.0	64.0	45.7	-20.7*	Maranate, 1982
Sichuan	J	29.0	64.0	45.7	-16.7*	Maranate, 1982
Phu Thok	K	18.1	32.7	17.8	0.3	In this study

* not accepeted

Remark; Pres. lat = Present latitude, Lat Diff. = Present latitude-Paleolatitude

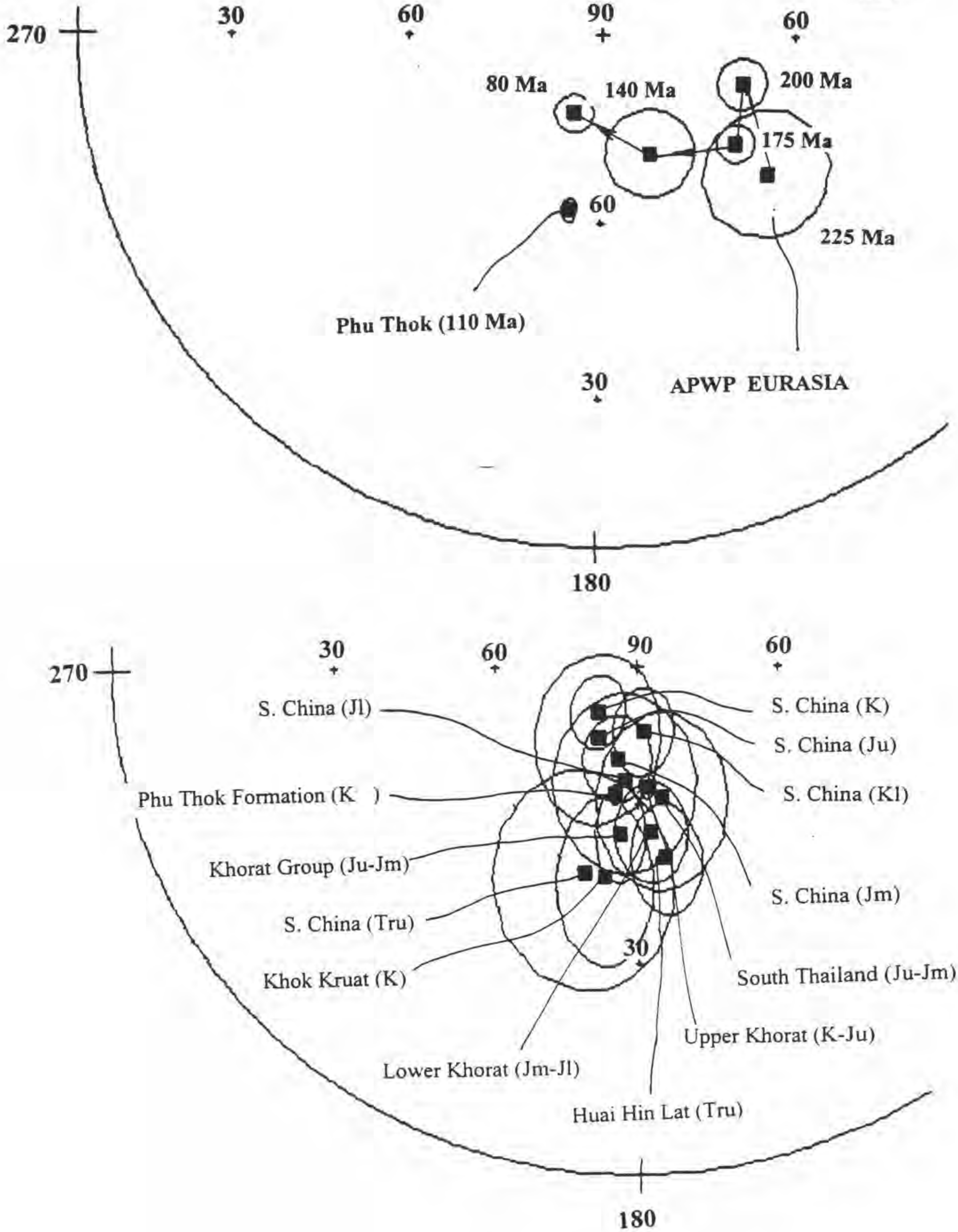


Figure 8.4 Correlation of Phu Thok paleopole with the APWP of Eurasia (up) and several plate (down)

cit.) argued that the different latitudes of all Khorat rock sequences related to the present position vary from -6.5° to +7.5° and average -0.49° (A_{95} = 4.53), similar to Yang's study. McCabe and others (1988) reported the latitude reference of Cenozoic basalt from NE Thailand at Ca.11 Ma higher than the present at about 6-7°. Therefore, all data presumably suggest the depositional area of the Khorat Group was at nearly the same latitude with the Phu Thok Formation deposit area. Nevertheless, this is shifted from the present position for about -1.4° to +1° in latitude.

The declination of Phu Thok samples at the Phu Thok and Phu Wua areas is certainly closed to the Mesozoic Indochina block (see Table 8.1). Earlier works such as those of Barr and Macdonald (1978), Bunopas (1981), Maranate (1982), Achache and Courtillot (1985), Chen and Courtillot (1989) and Yang (1992), indicated the declination of Indochina block ranging from 26° to 47°. It is obvious that Bunopas's Cretaceous and Barr & Macdonald' s Jurassic sites gave abnormally low declination values. The Cretaceous declination of 47° (Maranate, 1982) is quite greater than the Khorat Group mean of 37° (Maranate, op. cit.). Moreover, Yang (op. cit.) suggested that the declination of Late Triassic to Early Cretaceous Khorat varied from 26.6° to 39.5°. This conforms fairly well with this paper (29.6°). Therefore, it is concluded that all tectonic rotation of Khorat took place at least after the deposit of Phu Thok and Phu Wua rocks (or after Middle Cretaceous). The only paleomagnetic work of younger Mesozoic rocks in Indochina massif recorded by McCabe and others (1988) based on northeast basalt (< 11 Ma age), yield northward declination, therefore the rotation of the Khorat Plateau occurred approximately during 11 to 65 Ma.

2. Comparison with Shan Thai plate (or western Shan - Thai / Indochina microcontinent)

Not many paleomagnetic data of Middle - Late Mesozoic Shan-Thai rocks were quoted by Bunopas (1981) and Richter and Fuller (1996). In Bunopas (op. cit.)' s hypothesis, Shan-Thai and Indochina was collided since Triassic (or

Lower Jurassic by Enkin and others, 1992, and Charusiri, 1989). Therefore, the paleomagnetic pole of the younger rocks within those two microcontinental blocks should be similar at the same time. Bunopas (op. cit.) noted that the paleomagnetism of Middle-Late Jurassic gave the fairly reliable result. However, all data gave the closely similar pole position (i.e., 58.2° to 65.2° N, 170° to188° E), declination (i.e. 25.7° to 33°) and slightly different paleolatitude (+4° of the present) to the Phu Thok and Phu Wua samples (see also Table 8.2). It can be inferred that the stable, amalgamated landmass of Shan Thai and Indochina took place since at least Middle Jurassic until the time of deposition of these rocks at Khao Phu Thok and Phu Wua (Early Cretaceous). It is likely that the Bunopas (op. cit.)'s data on paleopole and declination of Cretaceous are pessimistic. However, he also suggested that during Mesozoic time, Shan-Thai was located at lower latitude than Indochina and most rotation during Jurassic resulted from tectonic rotation of northeastern Thailand before the Cretaceous.

Many reliable papers on paleomagnetism of younger Mesozoic of Shan Thai were proposed by Sasajima and others (1978), Barr and Macdonald (1979), Haile (1979), Yokoyama and Dharma (1982) and Haile and others (1983). All these data suggested that the declination is due northward and the pole position has been nearly at the recent pole since at least 23 Ma (Early Neogene). However, Richter and Fuller (1996) studied the Early to Middle Paleogene and Cretaceous rocks along the Sagiang/Shan fault area in eastern Burma. They interpreted the clockwise rotation of Shan-Thai and Indochina happened during Late Cretaceous - Early Paleogene (nearly 65 Ma). Therefore, the result of the 29.6° of declination which is assigned for the Phu Thok samples in the study area, is fit in this study and gave rise to the fact that the deposition of Phu Thok basin occurred prior to the clockwise rotation of the united Shan-Thai/ Indochina plate took place.

3. Comparison with South China plate

The South China Jurassic-Cretaceous poles were also a focus of this research. Their APWP were introduced by several geologists (see Yang, 1992 and Table 8.4 in this paper). Pole latitude data in Jurassic of several microplates in South China block from McElhinny (1969), Maranate (1982), Kent and others (1987), Enkin and others (1991b) and Yang (1992), are quite similar to those of the Khorat Group and the Phu Thok formation at the study area. South China Jurassic pole are, however, slightly different from those of the Indochina plate. In contrast, the APWP and VGP Cretaceous poles of the stable microplates, except those of south of South China along the Red River Fault including Yunnan (Zhu and others, 1988 and McElhinny,1969 in Maranate 1982), Qiangtang area (Otofuji and others, 1990), Chuxiong area (Funahara and others, 1992) and Kwantung (McElhinny, op. cit.), show higher pole-latitude (74.3° N , 215.7° E with A_{95} = 6.5° calculated APWP of South China Block by Yang and others, 1991 and Yang, 1992). However, these paleopoles of the above-mentioned Cretaceous rocks are still similar to that of the Khorat paleopole (especially in the rocks of Phu Thok and Phu Wua areas) . Enkin and others (1992) concluded that the contact of South China and Indochina probably occurred before Jurassic and their subsequent separation took place during Late Jurassic to Early Cretaceous. Therefore, during Jurassic Periods paleopoles of South China and Shan Thai microplates should have been very similar.

The South China paleolatitudes during Mesozoic all have substantial negative differences (lower latitudes) from present-day latitudes , and the Jurassic (& Triassic) differences are greater than the Cretaceous differences (see Yang, 1992). It is concluded that South China was located at about 20° N of present -latitude at least in Jurassic (10° N in Triassic) and nearly half (about 5-10° N) of that northward movement to 25° N probably took place during Cretaceous Period following the sinistral Red River Fault. The movement exceeded 1,500 ± 800 km (Yang, 1992) whereas the Khorat rocks were still located at about 20° of latitude until the Recent.

Likely to the paleopole, Jurassic and some Cretaceous paleomagnetic data of South China reveal the northeast declination whereas the Cretaceous rocks of the stable land of this plate advocated the NNE declination, such as Yangtze block- D= 19.1° (Chan, 1991) and South China Plate - D= 15.2° (Yang, 1992). In contrast, the Khorat Plateau has pointed to the northeastern declination since Upper Triassic to Late Cretaceous (including Phu Thok formation). Therefore, it can be interpreted herein that South China plate is less separated from Thailand (Shan-thai and Indochina), and most of the differential movement is caused by the activity of Red River Fault. It is evidenced that the movement is likely to take place within the Jurassic and Cretaceous Periods (Maranate and Vella, 1986 and Yang, 1992).

4. Comparison with Eurasia

According to the result of this study and of Enkin and others (1992) in Table 8.3, it is unreliable to correlate the VGP paleopole of the Phu Thok samples in the study area with the APWP of Cretaceous Eurasia. Furthermore, the Mesozoic rock poles are not closed to the APWP Eurasia in several Mesozoic rocks. It is also recognized that the contact of Eurasia with the study area (or the Khorat Plateau) never exists in Mesozoic Era. However, the pole of Eurasia during Cenozoic is regarded stable compared with that of the Indochina block.

Paleogeography of the Phu Thok rocks in the study area

From the overall data mentioned above, it can be concluded that the rocks at Phu Thok and Phu Wua areas are relatively closed to the Middle-Late Mesozoic Khorat Group. In Jurassic Period, Thailand and South China were parts of a single rigid continental block that rotated clockwise (Enkin, 1992 and Maranate, 1982). This single united continent is fluctuately located at latitude ranging from 15° to 30°N. Then the deposition of Nam Phong, Phu Kradung, Phra Wihan, and Sao Khua may have occurred since Early Jurassic to Late Jurassic. The South China Block began to move upward and the complete continental collision with the North China Block occurred during Late Jurassic (Yang, 1992). The South China Block subsequently moved to the north by sinistral movement of the Red River strike slip fault (see

Tapponnier and others, 1986, Yang, 1992) during Late Jurassic -Early Cretaceous. Prediction was made by the results gathered from the declination and different latitudes of Khorat and South China (Maranate, 1982, Enkin and others, 1992 and Yang, 1992). Clockwise rotation, $14.2° \pm 7.1°$ of South China related to Eurasia took place whereas the rotation of Thailand have not occurred (Yang, 1992).

At Lower -Middle Cretaceous time, sediments of Phu Phan, Khok Kruat and Phu Thok rocks in the area (this study), and Maha Sarakam with some Borabu (informal name-Piyasin, 1985) Formations, were deposited in the Khorat Basin in the middle part of Indochina continental block at latitudes of 17° to 18°N.

The clockwise rotation about $32.5° \pm 2.5°$ of continental Thailand at time before Tertiary is certainly supported by McCabe and others (1988) and Sasajima and others, (1978). In fact, the few angles of declination recorded in Neogene rocks indicated this clockwise rotation about 20° to 30° occurring prior to Early Neogene. The Richter and Fuller (1996) 's work is inferred by this study that the slow clockwise rotation of the Indochina/Shan Thai occurred during Late Cretaceous to Paleogene by effect of Asian-India gigantic continental collision. The rocks in the area and the other Mesozoic rocks are therefore rotated in that time and the late-stage uplift of the whole Khorat plateau causing the Phu Phan Range may occur in this episode (see Fig 8.5).

Tectonic reconstruction of the area

The geography of the Phu Thok formation at the area can be explained by plate tectonic reconstruction during Late Mesozoic (Bunopas, 1981). After the Early Cretaceous rocks justified by paleomagnetism (including Phu Phan, Khok Kruat and Phu Thok Formations) of Khorat Group were deposited and diagenetically lithified. The uplift of the western edge of the Khorat Plateau took place and was caused as a

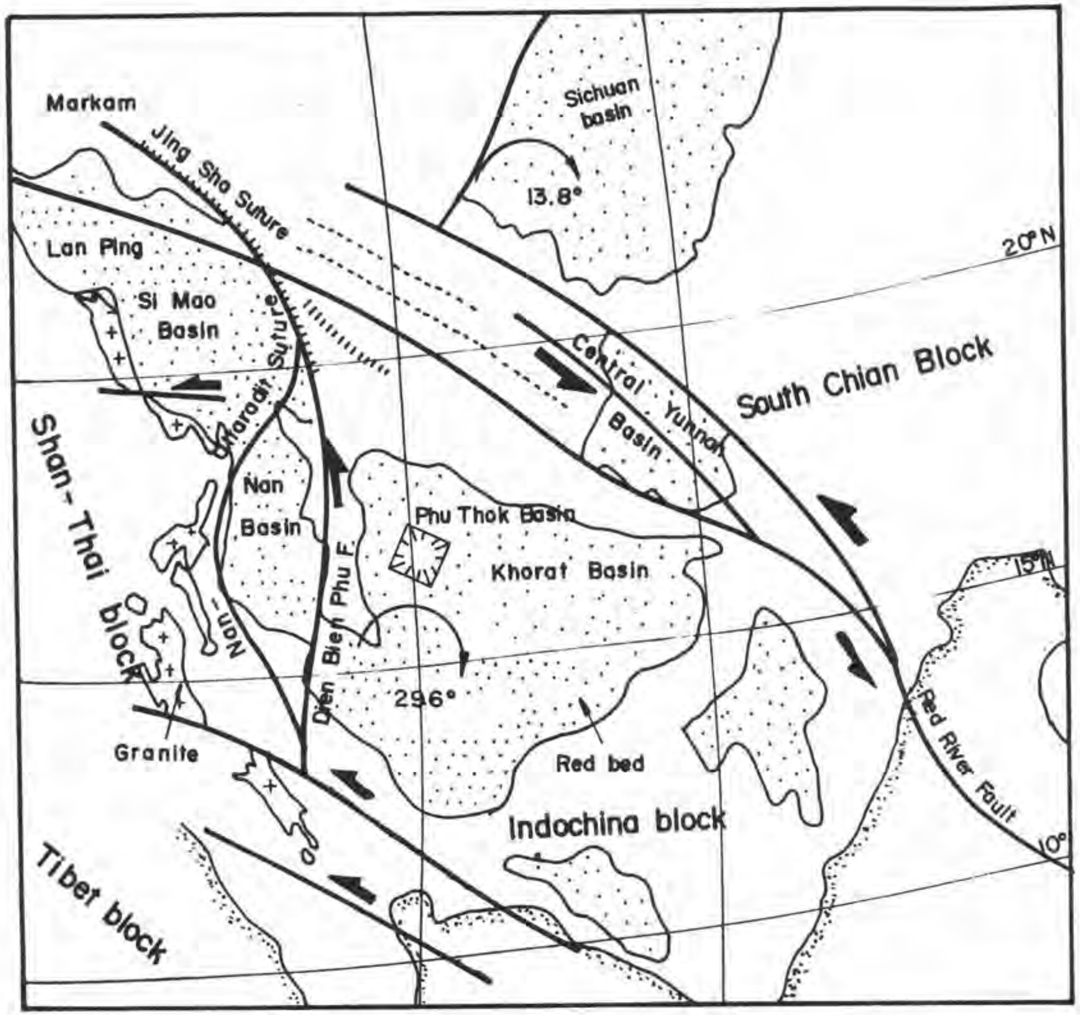


Figure 8.5 Simplified paleogeography of the Khorat Group during Early Cretaceous Period showing that the Phu Thok basin was located at present-latitude of 17° to 18°N. It is noted that the declination of Late Mesozoic rocks at about 18.9° (of South China in Yang, 1992) and 29.6° (Indochina, in this study) suggest the clockwise rotation of both plate, since Late Cretaceous to Recent. (the Phu Thok data- mean D= 29.6°, I=32.7°, present latitude of site = 18.1°N, paleolatitude of site = 17.8° ± 1.2°, paleopole = 61.9° N and 189.9°E with A_{95}= 1.8.

result of the collision of Shan-Thai and Western Burma in western Thailand (Bunopas, 1981). This evidence in that time fit the polarity alternation of magnetostratigraphy. The NW-trending Red River Fault and the other fault similar trending sets, which occurred since Late Triassic, were reacted during late Early Cretaceous. At that time, South China was also rotated (Yang, 1992). The tectonic compression might have constructed the gentle folding of rock strata older than late Early Cretaceous. Synclinal structure of Phu Thok, Phu Wua (and Phu Langka) might have occurred with the NW-trending and southward plunge, along to the general trend of the Khorat rocks. The NW- trending fault in the area might be subsidiary of the strike-slip Ta Khek Fault (a fault set of Red River Fault). These fault sets should have occurred postdating tectonic deformation, during late Early Cretaceous (Early Albian-Aptian). The subsidence of the eastern edge of Khorat Plateau (possibly in Laos and Cambodia) may have occurred during Early Cretaceous and the hypersaline water was infilled in structurally controlled E-W trending sedimentary basin during Middle Cretaceous or at the quiet long normal Cretaceous until Late Cretaceous. The uplift and deformation of the Phu Thok (folding and faulting) should have occurred as a result of the Early Cretaceous tectonism, therefore the Phu Thok during that time was located in term of altitude, above the brine deposit. Mostly Phu Thok anticlinal structure should have been completely eroded since Late Cretaceous. However, the steep cliff around the Phu Thok mountains may be interpreted as a result of the NW-trending consequent fault scarps occurred at least Tertiary and therefore the Phu Thok formation at the mountains may have uplifted again and remagnetization of N-S direction was carried in the rocks in that time.