CHAPTER VII

MAGNETOSTRATIGRAPHY

General

The magnetostratigraphy is based on the fact that from time to time the polarity of Earth's magnetic field has reversed itself. The normal polarity is represented in the northern hemisphere by northward declinations and downward inclinations. The opposite or reverse polarity state has southward declinations and upward inclination (Verosub, 1985 and Cox, 1986). In this study, the magnetostratigraphy is created from the polarity zone of each accepted sample in the rock sequence. The stratigraphic positions of the polarity are, therefore, relied on the stratigraphic column of the samples. The boundary of the polarity significantly depends upon the sedimentologic or tectonic application (McElhinny, 1973 and Verosub, 1985). Most characteristics of magnetostratigraphy is limited by the law of ISSC Internation Stratigraphic Guide (IUGS, 1979).

In the current study, the normal polarity is chiefly defined from the samples which have magnetic declination between 355° and 75° and inclination downward. The reverse polarity is identified by the magnetic declination between 175° and 255° with inclination upward. The variation of declination and inclination are believed to depend on the secular variation of the Earth magnetic field which fluctuated in each 10,000 year or less than (Cox, 1969). However, the other abnormal magnetic data, such as declination northward but inclination upward, are difficult to consider. In general, the simple identification of magnetic polarity of low latitude such as Thai Mesozoic rocks, are required from declination values whereas the inclination value is mostly the supporting data for interpretation (Maranate, 1982).

Magnetostratigraphy

1. Magnetostratigraphy of sections

The Phu Thok section comprises 67 normal and 4 reverse sample sites. However, when taking into account the accepted value at A95 (<20 when N=2-3) , only 60% of the samples are qualified. The remained 40% are mostly rejected for paleopole calculation. However, all samples are considered to yield the probably polarity, such as sample No. 38005 showing the cone of confident at ca. 24.6 and all the three specimens have northward declination and upward inclination, giving rise to the normal polarity.

The magnetostratigraphy of the Phu Thok section (Fig. 7.1) displays 4 bands of the normal and 3 bands of the opposite. At relief up to 45 to 46 m from the base, all samples (nos. 37001 to 37013) show the long normal polarity (or N1). It is noted that a sample (no. 38008) shows the ambiguous mixture of downward and upward inclination, however, it is believed to be the normal polarity sample. From magnetic declination and magnetic intensity, at least 13 cycles of magnetic secular variation are recognized in this unit. The stripes of reversal (R1 and R2) took place at two sites (nos. 37014 and 37016) at the relief (or the height from bottom) between 47 and 50 m. Both samples have mixture of reverse and (some) normal declination and weakly intensity. It is assumed to represent probably a short reverse on the long normal polarity. Then, two normal polarity (N2 and N3) is recognized (by sample nos. 37015 to 37041) at the relief between 51 and 93 m from the base with at least 11 cycles of secular variation of magnetism. In this range of normal zone, the probably normal (or reverse ?) polarity is shown at two sites (sample nos. 37021 and 37036) because they have mixed population of both normal and reverse inclination, and their declination is unclear.

In addition, the reverse stripe (or R3) is shown again in one sample (no. 37043) and probably forms the transitional zone of normal and reverse at one site

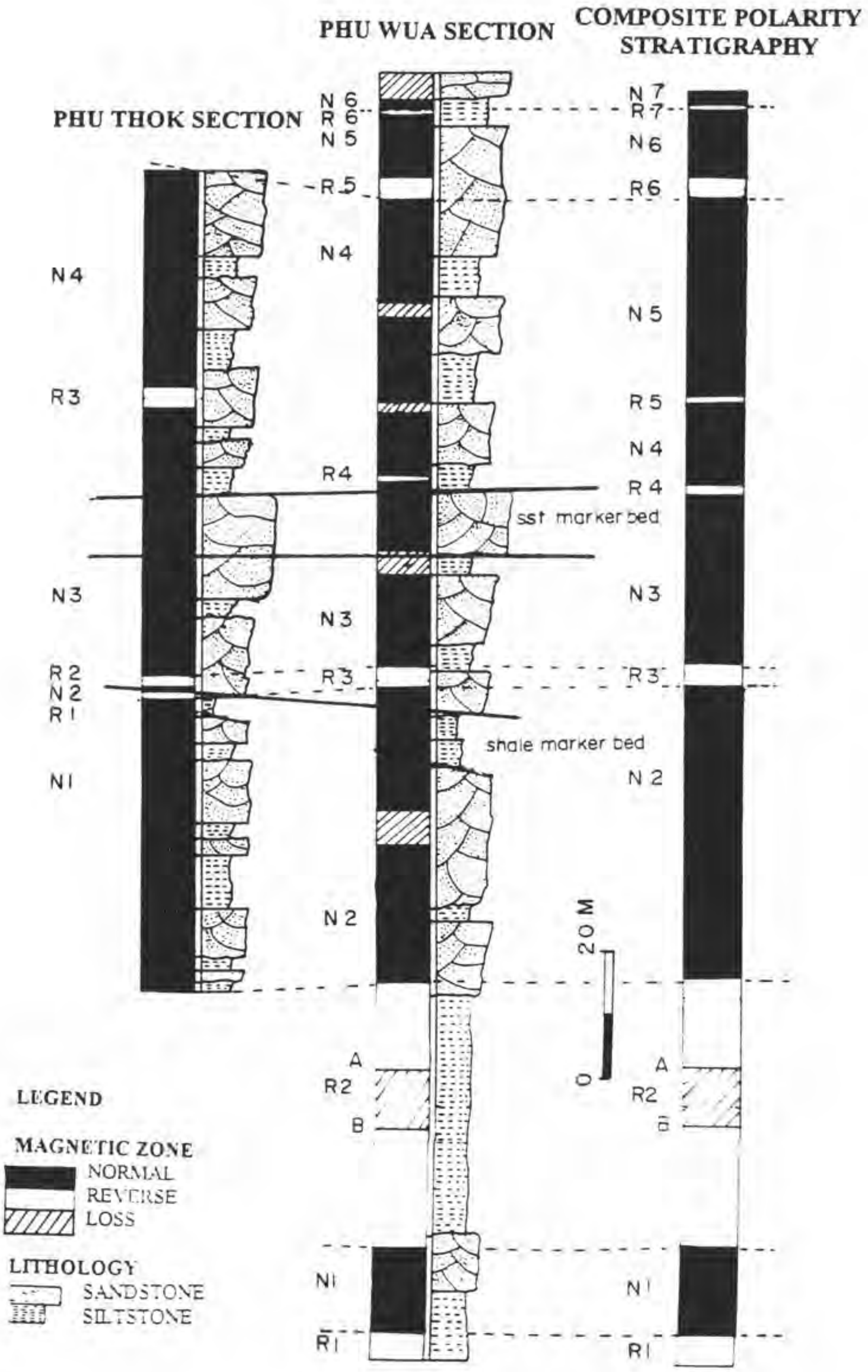


Figure 7.1 Magnetostratigraphy of the Phu Thok, Phu Wua and composite sections.

sample (no. 37042), at relief of about 94 to 97 m from the base. Then, the long normal polarity (N4) is recognized in few samples (nos. 37048 to 37060) at the relief between 98 and 130 m. It consists of at least 7 cycles of secular variation of magnetism. The other two samples (nos. 37057 and 37059) at relief 124 and 127 m from the base indicate the mixture of reverse and normal inclination but normal declination, therefore, the probably normal polarity (or reverse?) is assumed in the upper sequence.

The overall picture of the magnetostratigraphy of the Phu Thok section is mainly consisted of normal polarity with some reversal bands at the middle part. Sequence of the alternating polarity is the long normal polarity zones (95%) are regularly alternated by short reverse. Mostly reverse polarities bands is only occurred in the fine-to medium grained sandstone strata.

The Phu Wua section consists mainly of 54 normal and 15 reverse samples sites. When considering the accepted value at A_{95} (<20 when N = 2-3), only 45% of the samples are qualified for paleopole calculation. However, all samples are considered the probable polarity. The magnetostratigraphy of the Phu Wua section (see Fig. 7.1) is relatively similar to that of the former section. It consists of 6 bands of normal and 6 bands of the reverse. The first probably reversal band (or R1) is recognized by a sample (no. 31086) at above 1 m from the base. At the relief from the base up to 4 to 14 m (or sample nos. 31083-31085) indicate the sequence of normal polarity (or N1). Above this normal sequence, the long reverse band (R2A) exists which is typically recognized at relief between 15 and 31 m. Three samples (nos. 31080 to 31082) reveal this reversal band. It is noted that the sample loss is revealed at relief between 32-45 m. It may be continuously overlied by the reverse band (R2B) of the other three sample (nos. 31076 to 31079) at relief about 46 to 58 m. At least 2 cycles of secular variation of reversal magnetism are shown in this polarity. Then, the long normal polarity (N2) zone is recognized by six samples (nos. 31069 to 31075) at relief between 59 and 105 m from the base with at least 6 cycles of secular variation of magnetism. However, due to the loss of data at relief between 77 and 86 m from the base the polarity of the samples cannot be justified. The last sample (no. 37175) is characterized by upward inclination and northward declination. It is interpreted to represent the transitional zone. Then, the short reverse (or R3) from a sample (no. 37168) is represented at 106 to 109 m from the base. Above the short reverse zone, the stripes of normal (N3) took place at sample No. 37130 to 37152 at the relief between 110 and 145 m, indicating at least 3 cycles of secular variation. The loss of data is located in the very fined-grained sandstone bed at relief about 120-123 m from the base.

The other two reverse samples (nos. 37145 and 37146) (R4) occur at the top of thick sandstone strata at about 151 m from the base and is covered by the long normal polarity (N4) of eighteen samples (nos. 37111-37145) at the relief between 128 to 135 m (or 38 m thick) on the dipslope from the base. This zone has at least 15 cycles of secular variation of magnetism. In this range of the normal zone, the probably normal (or reverse?) polarity is shown by a sample site (no. 37124) due to the unclear declination direction. It is important to note that there is the loss of data of rock sequence between sample nos. 37122 and 37123. In addition, the reverse stripe (R5) is shown again in one sample (no. 37109) and probably to the other transitional zones of normal and reverse exist at sample nos. 37108 and 37110, at relief about 128 to 130 m from the base. Then, the long normal polarity zones (N5 and N6) are detected in 8 sample sites (nos. 37001-37009). The only one reverse polarity (R6) is intercalated at a sample site (no. 37102), at the relief of about 175 m. The long normal polarity zone contains at least 4 cycles of secular variation of magnetism. Three sample sites (nos. 37101, 37105, and 37106) give rise to the probably normal polarity since they have mixture of reverse and normal inclination and northward declination in the individual specimens.

The overall picture of the magnetostratigraphy of the Phu Wua section is composed of two characteristic of polaritied alternation. The lower mainly composes of long reverse polarity alternated with one normal polarity zone (Fig 7.1). The upper part of the section is the irregular alternation of the long normal polarity zone (90%) and short reverse. Mostly reverse polarities bands in the upper sequence is only occurred in the fine-to medium grained sandstone strata whereas the lower sequence, they found in the very fine-grained sandstone.

2. Correlation of both sections

A composite magnetostratigraphy of the Phu Thok formation at Khao Phu Thok and Phu Wua areas is correlated by a polarity zone of both sections (Fig. 7.2). The simple correlation can come up with the application of the lithological marker bed. The bed is recognized by thick bedded, medium- to coarse- grained sandstone with large-scale cross-bedding in the middle part of the Phu Thok sequence and thin-bedded shale only occurring at the middle-lower part of the sequence. In this hypothesis, it is clear to correlate the N1 of Phu Thok section with the N2 of Phu Wua section. The stripe reversals of R1 and R2 at Phu Thok formation are located right at the thin, and the well-bedded sandstone, at above the marker bed shale up to 2-4 m is believed to be correlated with the R3 at well-bedded sandstone, located immediately above the shale bed up to 5 m of the Phu Wua section.

In the upper sequence, the correlation of short reverse bands of both sections are currently uncleared. However, it tentatively represents the long normal zones of Phu Thok section (N3, N4 and N5) and can be well correlated with N3 and N4 of Phu Wua section. The top of Phu Thok section is characterized by transition zone of polarity (referred herein by the varied magnetic vector at sample nos. 37057 to 37060). It is, therefore, probably correlated with the lower part of the R5 at Phu Wua section.

3. Composite magnetostratigraphic zonation

From the correlation of 2 magnetostratigraphic columns, the composite magnetostratigraphy and polarity zones of the rocks sequence in the area can be established. The composite magnetostratigraphy points to dominantly normal polarity with 1 relative long reverse interval near the bottom and 6 brief reverse intervals higher up. The upper part of this magnetostratigraphy show the alternations of long normal (>90%) and short reverse (5-10%). The more frequency of polarity alternation is the uppermost part. However, the lower sequence of composite magnetostratigraphy is mainly of long reverse (70-80%). The magnetostratigraphy consists principally of 4 polarity zones, namely PT-A Reverse, PT-B-Normal , PT-C Normal and PT-D mixed Polarity Zones (see Fig. 7.2).

A. PT-A reverse polarity zone

This polarity zone represents the lowermost zone of the sequence. It is limited by the fine-grained sandstone strata or the lowest part of the lower lithological member. The polarity zone has a thickness of more than 60 m, mostly comprising the reverse polarity sample. The only normal polarity zone is located at the lower part, at a relief of about 4 to 14 m from the base. R1, R2 and N1 of the composite section are recognized in this zone.

B. PT-B normal polarity zone

This zone overlying the PT - A Reverse Zone is marked at the bottom by the boundary of Phu Thok lower member and roughly at the top by the marker bed, thick-bedded medium- to coarse- grained sandstone. The thickness of this zone is about 87 and 81 m at Phu Thok and Phu Wua section, respectively. It is mainly composed of normal polarity topped up with only one reverse polarity. This reversal (3 m thick) is located above the shale marker bed. N2, N3 and R3 are included in this zone.

C. PT-C normal polarity zone

This zone is the upper part of the sequence. Its bottom is limited by the sandstone strata above thick bedded of sandstone marker bed and its top is marked

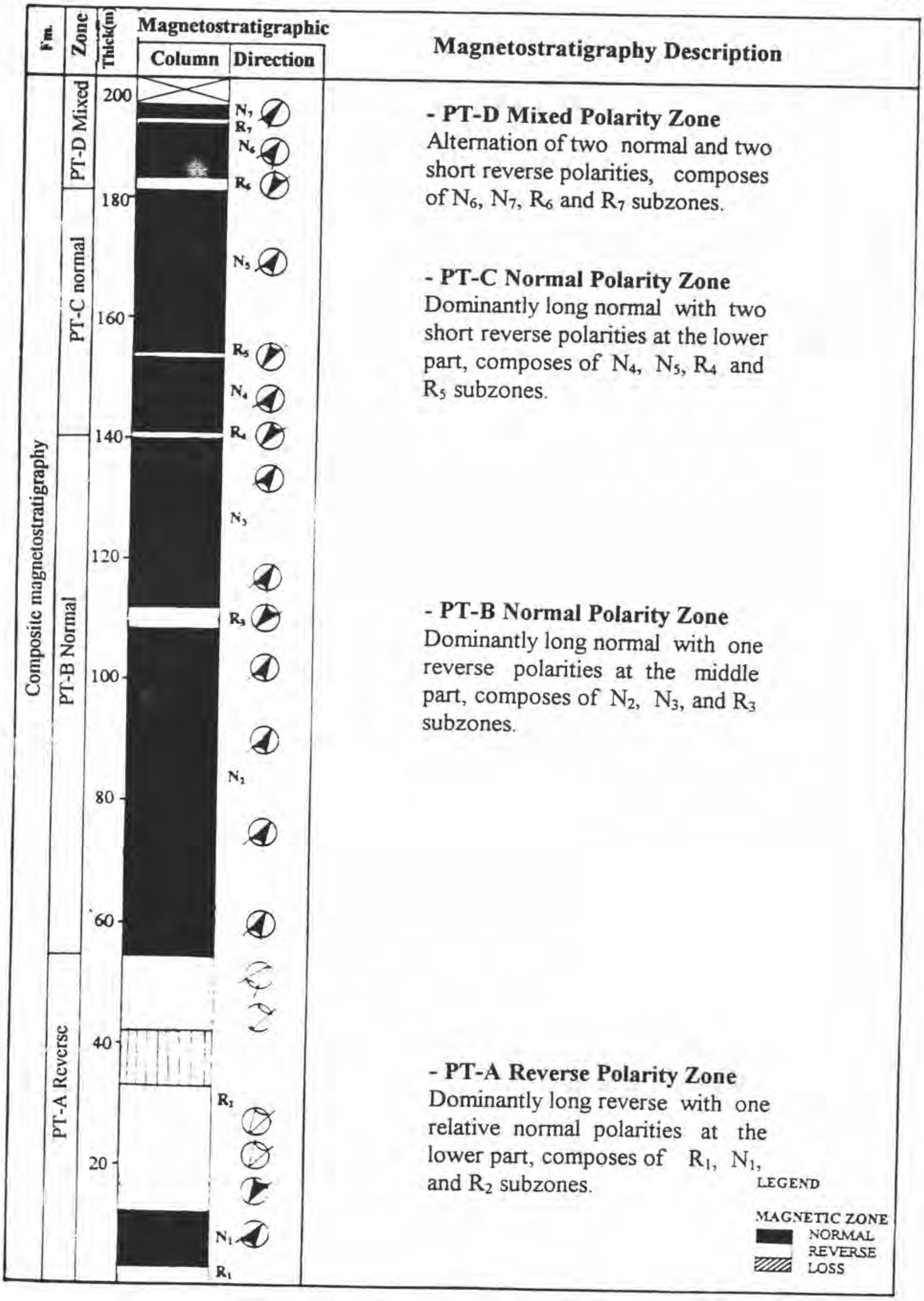


Figure 7.2 Composite magnetostratigraphy of the Phu Thok sequence at Phu Thok and Phu Wua areas.

by the fine-grained sandstone with strongly ripple structures and desiccation cracks. The thickness of this zone is about 36 and 47 m at the Phu Thok and the Phu Wua sections, respectively. The composite magnetostratigraphy is mainly composed of a long stripe of normal and 2 short reverse polarities at the lower part. These reversal bands (2-3 m thick) are located in very fine-grained sandstone right above the top of sandstone marker bed of the Phu Thok and Phu Wua sections. N4, N5, R4, and R5 of the composite section constitute this zone.

D. PT-D mixed polarity zone

This zone is the uppermost part of the sequence whose bottom is limited by the strongly ripple-structure and desiccation-crack sandstone beds below 8-9 m from the uppermost sequence of the Phu Thok section. The thickness of this zone is about 8 and 14 m at the Phu Thok and the Phu Wua sections, respectively. The composite magnetostratigraphy is composed of intercalated 2 normal and 2 reverse polarities. The reversal bands (3-5 m thick) are located below 2 m and 12 m from the top of composite lithostraitgraphic sequence. N6, N7, R6 and R7 of the composite section are applied to this zone.

The overalll magnetostratigraphy in this study is similar with the pilot study of magnetostratigraphy (Pattarametha and others, 1988). They separated the magnetostratigraphy based on polarity zones into 3 parts, the upper, middle and lower parts. The upper part of the pilot study can be corrlated with PT-C and PT-D zones. The middle and some lower parts of them are stratigraphically correlated with PT-B zone, but, however, These parts are mainly reversal polarities. They are not similar with the PT-B zone. The lower part of Pattarametha works are stratigraphically correlated with PT-A zone, however, the result of paleomagnetic data is slighly diffent.

Magnetostratigraphy Dating

The composite magnetostratigraphy analyzed can be correlated to some extent to the Geomagnetic Polarity Time Scale of IUGS (1987) and Geomagnetic Polarity Time Scale of Geological Society of America (1988). The very long normal of late Early to early Late Cretaceous is rejected at this stages due to the fact that the composite magnetostratigraphy of both Phu Thok and Phu Wua shows some reverse polarities. Late Jurassic is also rejected, because the standard in that time which reversal dominant (more than 50%) is unlikely to this magnetostratigraphy. Late Cretaceous is also rejected because the age is chronogeologically younger than Maha Sarakam Formation (see chapter VIII). Two plausible correlations with the Cretaceous Geomagnetic Polarity Time Scale are therefore proposed. The most probable correlation is from the age range from Early Cretaceous (Hauterivian to Valanginian or from chron M4 to middle of chron M11) and the second alternative correlation is suggested by the age range of late Early Cretaceous (Lower Aptian to Upper Hauterivian or from top of M0 to middle of chron M5). Figure 7.3 shows such a correlation.

1. Most probable correlation (Early Cretaceous)

The correlation begins from the bottom to top (Fig. 7.4). At the PT-A reverse zone, the long reversal (or R2A and R2B) is correlated with that of the upper part of chron M11 (CM11) with age of about Late Valanginian or 122 to 123 Ma (IUGS, 1987). The lost samples are, in this case, assumed for the reverse polarity. Therefore, the lowest normal N1 may be correlated with the M11 band at the middle part of CM11 at age of approximately Late Valanginian or 123 Ma (IUGS, 1987). Above the reverse band, the PT-B normal zone, consisting of long normal N2 and N3 with intercalation of a brief reverse (or R3), is believed to be correlated with the dominantly normal zone of CM8 to CM10N. The short reverse band (R3) is probably correlated with a brief reversal at between CM8 and CM9. The normal and reverse polarities of PT-C normal zone are probably assumed to conform with the dominantly

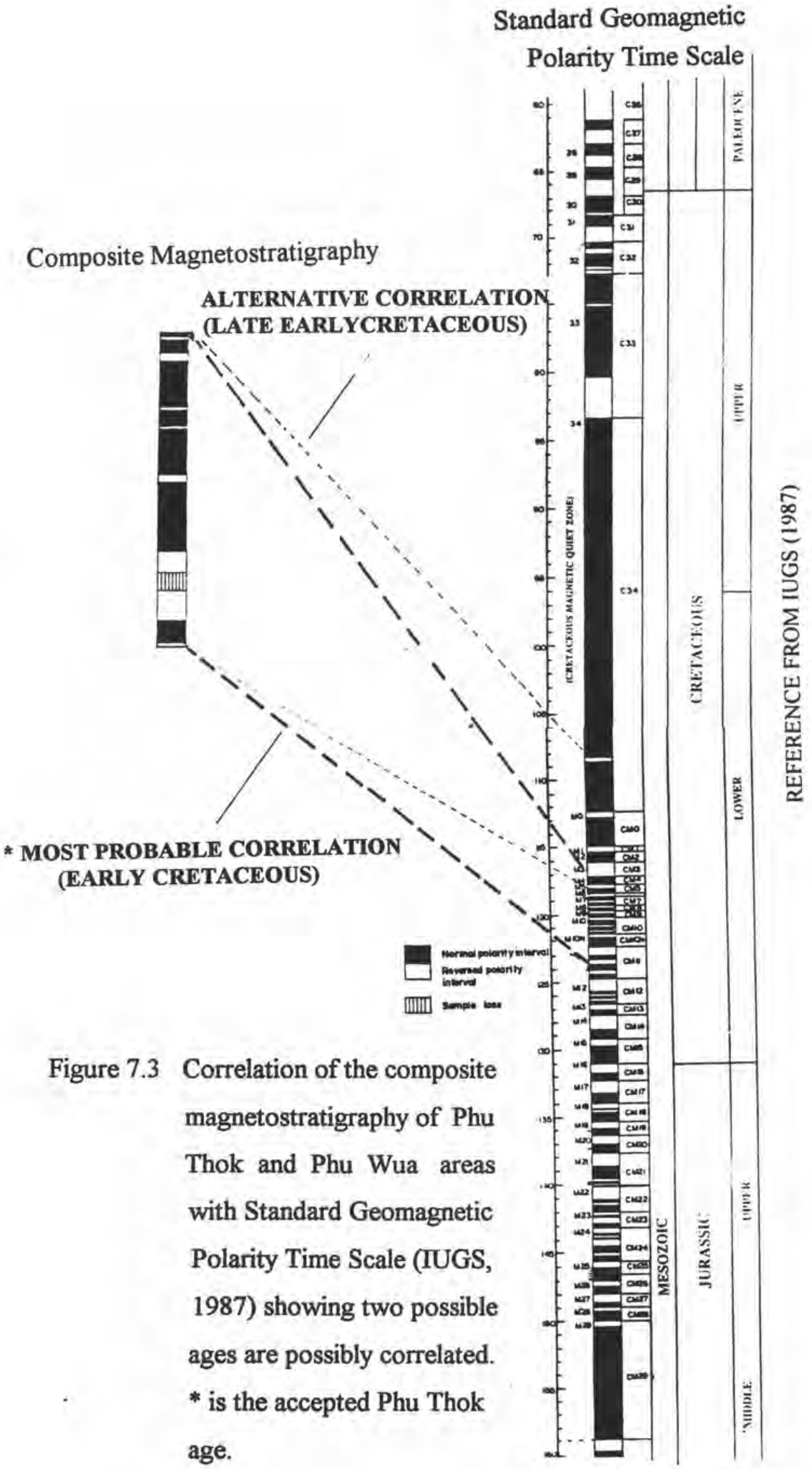
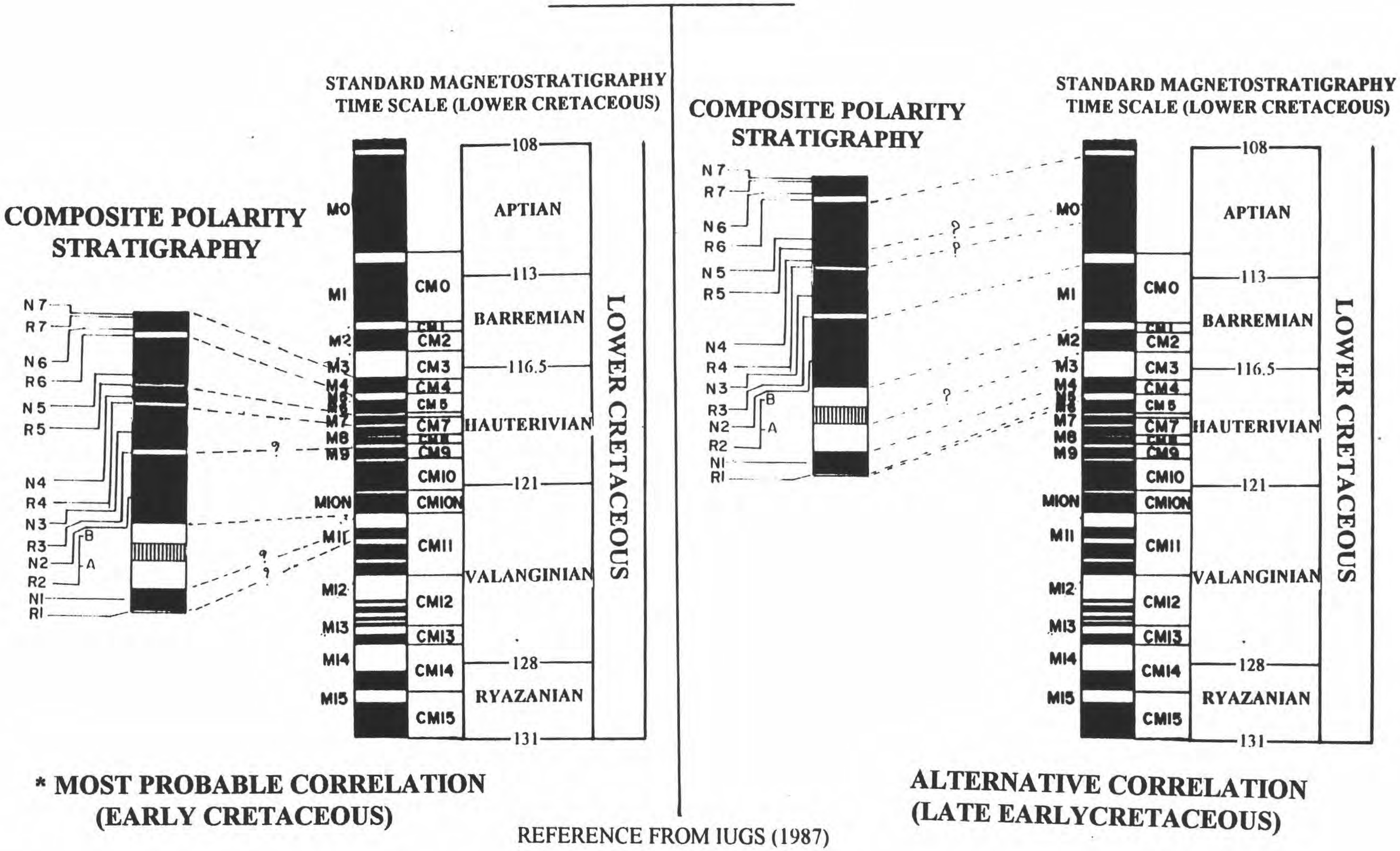


Figure 7.3 Correlation of the composite magnetostratigraphy of Phu Thok and Phu Wua areas with Standard Geomagnetic Polarity Time Scale (IUGS, 1987) showing two possible ages are possibly correlated. * is the accepted Phu Thok age.



Normal Polarity

Reversed Polarity

Sample loss

Figure 7.4 Correlation of the composite section with both proposed ages from the standard magnetostratigraphy (IUGS, 1987).

normal zone of lower CM5 to CM7. At least 2 short reverse bands at the PT-C zone are likely to be related with the brief reverse at CM5 to CM7 at an age of about Early Hauterivian or 119 Ma (IUGS, 1987). The PT-D mixed zone may be correlated with the uppermost of CM5 to CM4, suggesting the range of age from Middle to Late Hauterivian or 117 to 118.5 Ma (IUGS, 1987). The thicker reversal of the zone may have been related with the reversal at the top of CM5.

2. Alternative correlation (late Early Cretaceous)

The correlation commences at the PT-A reverse zone. The long reversal (or R2A) is believed to be well correlated with that of chron M3 (or M3 band) with the age of about Late Hauterivian or 116 to 117 Ma (IUGS, 1987) (see Fig. 7.4). However, the unavailable sample is believed to have normal polarity (or M2). The lower normal (N1) and reverse (R1) band may conform with the normal chron M4 (or M4 band) and the upper of chron M5 (or M5 band) with the age of early Late Hauterivian or 117 and 118 Ma (IUGS, 1987), respectively. The reverse R2B is inferred to correlate with the reverse chron M1. Above the reversal band, the long normal (N2) and a brief reverse (R3) are referred to correlate with the range of normal Chron M0 (or M1 band), and reverse band R3 is probably correlated with a brief reversal at the upper chron M1, of an age about Early Aptian or 112 Ma (IUGS, 1987). The dominant normal and transitional bands of PT-C normal zone are probably assumed to fairly well correlate with the M0 band. The 2 short transitional (reverse) bands at the PT-C zone is, though unresolved at present, may have been interpreted herein as part of the long normal polarity. The PT-D mixed zone may correlate with the uppermost part of the normal M0 and the overlying reverse M0, suggesting the age range from Early to Late Aptian or 108 to 112 Ma (IUGS, 1987). The lower part of the reversal band of the composite magnetostratigraphy may have been related to the standard reverse polarity whereas the upper reversal band (or transitional band) in the composite section may be herein interpret to represent as part of the normal band.

3. Proposed age of rocks using magnetostratigraphy

It is obvious that magnetostratigraphy in the Phu Thok study area derives from the data of rocks dominated by continental influence whereas that of the standard is of marine. Since deposition in the marine environment is smoother than that of the continental deposit. Therefore, the disappearance of some polarity bands in magnetostratigraphy of the continental areas including Phu Thok should be referred to more brief and violent erosion in the continent than that of the marine deposit. Furthermore, the regularity of thickness in marine deposit should better than that of the continent. Therefore, some polarity zones in the Phu Thok magnetostratigraphy are thinner or thicker than those of the standard. The correlation of magnetostratigraphy in continental area using the characteristics of alternation of polarities as well as the similarity of both magnetostratigraphy have to be carefully applied. Furthermore, historical geology during the deposition significantly causes the characteristics of alternations of both polarities (i.e., several short episodes of high tectonism give rise to high frequency of polarity alternations) is well considered.

The characteristic of magnetostratigraphy elucidates that the age of Phu Thok formation is possibly limited between late Early Cretaceous and Early Cretaceous. . After comparison of composite magnetostratigraphy with the Geomagnetic Polarity Time Scale, results of the Phu Thok formation show two plausible correlations (both likely to fit within 90 % stratigraphical similarity) with the Cretaceous Geomagnetic Polarity Time Scale (see Fig.7.3). One is from Early Cretaceous (late Valanginian-Hauterivian, 117-123 Ma of IUGS, 1987 or 125-133 Ma by Geol. Soc. of America, 1988) and the other fits in late-middle Early Cretaceous (Upper Hauterivian-Aptian, 108-118 Ma of IUGS, 1987 or 117-126 Ma of Geol. Soc. of America, 1988). However, the confusion in correlation of some polarity bands of both probably age ranges are also discussed.

Generally, all of the PT-A , PT-C, and the PT-D polarity zones are clear to correlate with the Early Cretaceous standard at about 117 to 123 Ma (see Fig. 7.4).

The question is the absence of the other short reverse in the middle part of the Phu Thok & Phu Wua composite section. The other is the longer band of reversal band (R2) which is not found in the standard scale. Furthermore, the polarities of the lost sampling between R2A and R2B are confused. In this correlation, this lost band is proposed as part of the long reverse band. However, the lost rocks may have some normal polarities. From this reason, it is slightly doubtful for this proposed age.

On the other hand, the magnetostratigraphy is quite clear to correlate with late - middle Early Cretaceous of magnetostratigraphy standard, especially in the lower part (see Fig. 7.4). On the basis of stratigraphic correlation, all of the sections can be correlated with the lower sequence of the standard, particularly the R1. The lost sample which is expected to be the normal polarity is however well correlated with the lower part of standard magnetostratigraphy. It is probable that the expected polarity is more appreciated than the former age. The only question arises when the transition bands of R4, R5, and R7 not found in the standard, are encountered. The R7, therefore herein, represents the uppermost short reverse and is defined as the erroneously interpreted data because the fluctuated reverse direction would not be shown in this time. The R4 and R5 bands, which are also the short transitional (or reversal?) bands on the long smooth normal, are likely to be parts of the somewhat long normal. From these evidences, this proposed age still have little argument.

From the correlation, although the evidence shown in the second hypothesis seem to be the possible polarity in the Phu Thok section which can be better correlated with the standard than the first hypothesis. However, on the basis of magnetostratigraphic character (such as the reversal frequency and polarity alternation) of standard magnetostratigraphy, it is suggested that the first hypothesis be better correlated with the standard than the second. Because the late Early Cretaceous magnetostratigraphy is defined from the time near the quiet normal Cretaceous, thus, the effect of reversal frequency is hardly occurred and is not consistent. Moreover, the Phu Thok have more reversal band and alternation of long normal zone and short reverse (in the upper-middle part) is regularity. Therefore, the second hypothesis (near the quiet zone) is not magnetostratigraphically correlated with the composite section whereas the magnetostratigraphic character of the first hypothesis can be fit in the Phu Thok magnetostratigraphy. It is regarded that the age of Phu Thok is about Early Cretaceous.

Tectonics evidence during the Phu Thok deposit should have occurred as result of a change in depositional environment reflecting alteration of fine-to-medium-grained sandstone and very-fine grained sandstone. Furthermore, sedimentary structure and characteristic of both rocks is quite different. Moreover, the unconformably overlying rocks is the Middle Cretaceous Maha Sarakam Formation which occurred during very mild tectonism (indicating by the long normal polarity). Therefore, the second probably age which is located nearby a long normal polarity (suggesting low energy of deposition) is not fitted with the tectonic event whereas the magnetostratigraphy of first possible age is concordant to geology and tectonism in the expected time.

The pioneer paper of Pattarametha and others (1988) and Bunopas and others (1989) suggested that the Phu Thok magnetostratigraphy consists of 12 reverse and 13 normal polarities zone and can be correlated with the Late Jurassic to Early Cretaceous (Kmmeridgian-Valanginian) of Cox and others (1982)' s standard. Their ages are older than that of this study. The appropriated temperature they applied to demagnetize the secondary magnetic component is 250°C which is required from their rock magnetism and demagnetized test of some samples. In term of the correlation of measuring section, the pioneer works gave the only result of magnetic zone. The proposed age of the Phu Thok in the study area is assigned by Pattarametha as Late Jurassic to Early Cretaceous (131-155 Ma by standard of Cox and other, 1982). The long normal and short reverse polarities in the upper part of their studied were assigned with the age of 131-139 Ma (absolute age from Cox and others, 1982 ' s standard). The mainly reverse in their studied were related with standard as age about 139-145 Ma and the lower part were assumed the age of 145-155 Ma.

However, The difference in the results is probably due to the difference in methodology and sedimentological/stratigraphical correlation of measuring sections. In term of the correlation of measuring section, the current study strongly rely on both detailed lithological study and paleomagnetic result to create the composite section. Samples collection in the study is more frequency than the pilot work and some loss section in the pioneer study are also collected. The 40% of total samples are demagnatized test by progressive demagnetization (temperature range 100°- 680°) and all sample are tested the demagnetization behavior in several temperature test. Appropriated temperature to demagnetized the Phu Thok and Phu Wua samples (in this study) is higher (at about 350° to 500°) Software programme are also helpful in the discussion on the polarity of each sample site in the study.

However, the both result is generally similar with the other. It can be certainly proved that the Phu Thok age by magnetostratigraphy should be limited by Early Cretaceous to Late Jurassic or/to Early Cretaceous.

4. Rate of sedimentation using magnetostratigraphy

Calculation of sediment influx to the basin (Phu Thok area) can be done on the basis of magnetostratigraphy. If the proposed age of Phu Thok rocks is correct (i.e. 117-123 Ma) and the estimated thickness (200 m) is applied, then the rate of sedimentation to the basin can be justified, *ca.* 33 m/Ma. This value is, however, quite different from that of Bunopas and others (1989) who proposed 8 m/Ma. Such a contrast (25 m/Ma) occurs as a result of the application of different age range of Phu Thok sedimentation and the estimated thickness. It is assumed that the studied rock sequences either bear the continuous deposition or have the hiatus not exceeding 10,000 years (Cox and others, 1982), giving rise to the overall appearance of polarity zones, or another words all subchrons of the magnetostratigraphy still exist and corresponding to those of the standard. This investigation suggests that rates of Phu Thok sedimentation did not equal in the study area. In the lower sequences which comprise very fine-grained sandstone to siltstone, the sedimentation rate is stronger- 50-60 m/Ma (see R2 in Fig. 7.4) whereas it become milder (20-25 m/Ma) in the upper sequence with dominated fine- to medium grained sandstone strata. This indicated the continental deposition of unequal sedimentation rate or implies the difference in environment of deposition. However, in order to make a conclusion on this, the paleoenvironments of the Phu Thok sediments have to be visualized in detail.