# CHAPTER 5
# DISCUSSION

## 5.1 Depositional environment of organic mater

The organic petrography, total sulphur (TS), TOC/TS ratio, Pr/Ph ratio, Pristane/n$C_{17}$ versus Phytane/n$C_{18}$ plot and $C_{27}C_{29}$ regular sterane distribution were employed to indicate depositional environment of organic matter.

### Fang basin

The organic matters of the Fang-MS well samples are dominated by liptinite with only minor amounts of huminite derived from land plants. The overall organic matter composition of the sample corresponds to type I kerogen with a subordinated proportion of type II kerogen. Small amounts of framboidal pyrite can be found in every sample. Such an organic matter composition is similar to the organic matter in freshwater (to slightly brackish) lacustrine mudstones (and oil shales) in other rift-basins onshore Thailand (Sherwood *et al.*, 1984; Cook and Sherwood, 1991; Ratanasthien *et al.*, 1999; Petersen *et al.*, 2006). The samples are interpreted to have formed in freshwater but presence of terrestrial organic matter points to a consistent influx of higher land plant material (up to 14.8 % huminite), maybe duo to transportation of higher land plant to lake. The structuraless, compact fluorescing AOM and the fluorescing AOM in the samples may appear to be more structured, which could be caused by a restricted reworking of the organic matter.

The sulphur content (TS) is usually low with relatively high TOC/TS (=C/S) ratios, generally ranging from ~5–8 (Figure 5.1). The low sulphur content is a typical characteristic of organic matter deposited in non-marine environment. Nevertheless, the detected TOC/TS ratios in Fang-MS well could imply slightly or occasionally brackish conditions during deposition. The presence of framboidal pyrite indicates reducing condition in the sediment.

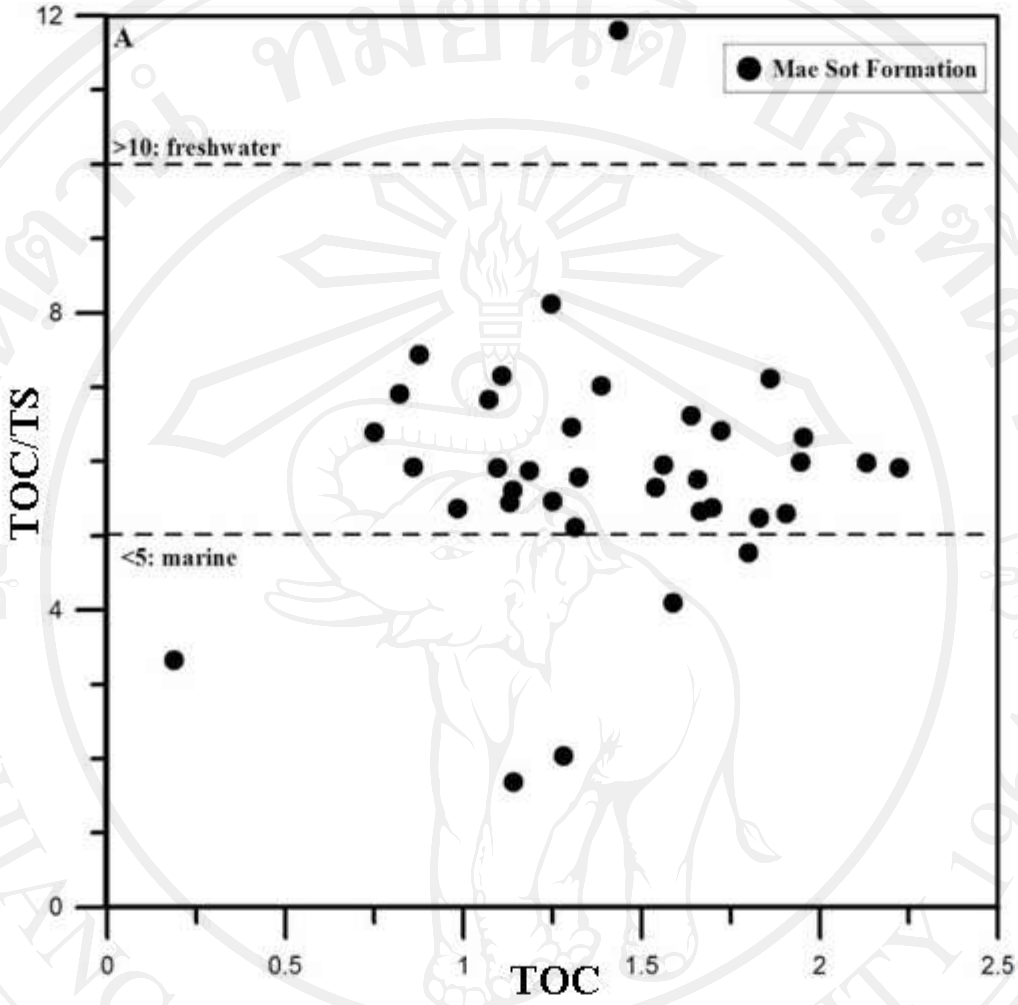


**Figure 5.1** TOC/TS versus TOC plot showing relatively high TOC/TS ratios ( ~5-8) of the samples from Fang-MS well indicating mostly blackish origin (TOC/TS boundaries from Berner and Raiswell, 1984)

The Pr/Ph ratios are increased from 1.50 to 3.02 which also indicate sub-oxic condition. The Pristane/$nC_{17}$ versus Phytane/$nC_{18}$ plot (Figure 5.2) of samples fall within or close to the oxidizing environment field and indicated a high biodegradation effect and low in mature sample.

From the $C_{27}$, $C_{28}$ and $C_{29}$ regular steranes triangular diagram can be indicated as lacustrine to terrestrial environment (Figure 5.3). Although the depositional conditions allowed preservation of organic matter at the lake bottom and may affected from brackish condition, the relatively low TOC contents may be related to the availability of oxygen during deposition. The observed orange and brownish fluorescence colors may further suggest some degree of oxidation of the organic matter.

**Na Hong basin**

The organic matters of the Na Hong samples are dominated by liptinite with high proportion of huminite (up to 28.9 %). The liptinite consist mainly of lamalginite, liptodetrinite, telalginite, resinite, fluorescing AOM, sporinite, exsudatinite and cutinite.

The Na Hong oil shale are interpreted to have formed in freshwater but presence of terrestrial organic matter points to a consistent influx of higher land plant material (up to 28.9 % huminite), maybe duo to nearby vegetated mire areas. The high preservation (generally high TOC contents) indicates dominantly oxygen-deficient lake bottom conditions. The lamalginite is filamentous and considered to originate from *Pediastrum* (Sherwood *et al.*, 1984; Cook and Sherwood, 1991). The *Botryococcus*-type telalginite indicates freshwater to brackish condition (Moldowan and Seifert, 1980; McKirdy *et al*., 1986). The coaly mudstone samples are humic (Type III kerogen) with occasionally high liptinite contents (terrestrial Type II kerogen). The overall organic matter composition for the sample corresponds to type I with a subordinated proportion of type II and III kerogen which are commonly associated with coals and fluvial deposits (Carroll and Bohacs, 2001) or forest swamp environment (Ratanasthien *et al*., 1999).

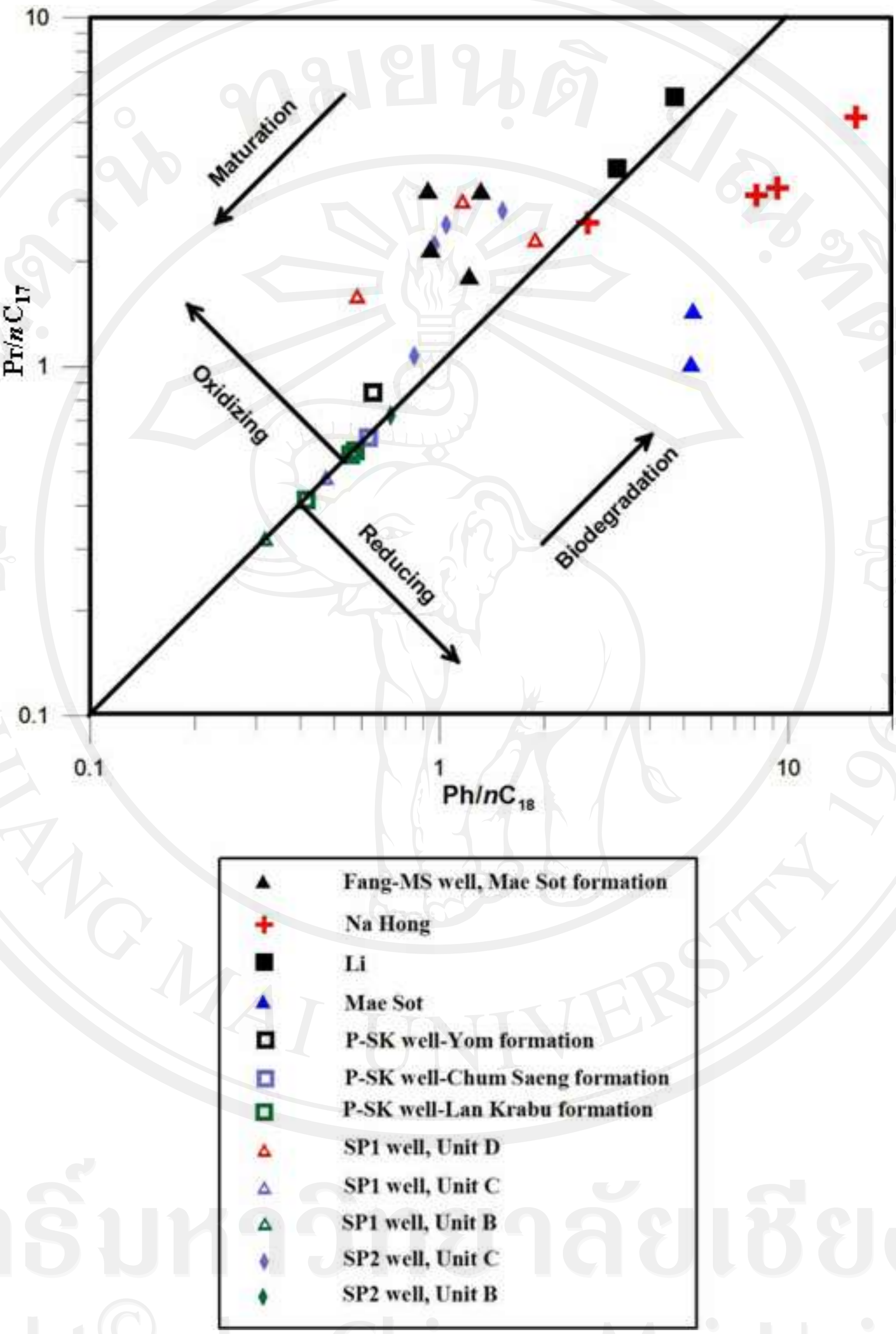


**Figure 5.2** A Pr/$nC_{17}$ versus Ph/$nC_{18}$ plot of samples studies. The plot is used to indicate redox depositional environments (after Lijmbach, 1975; Peters *et*, *al*., 1999).

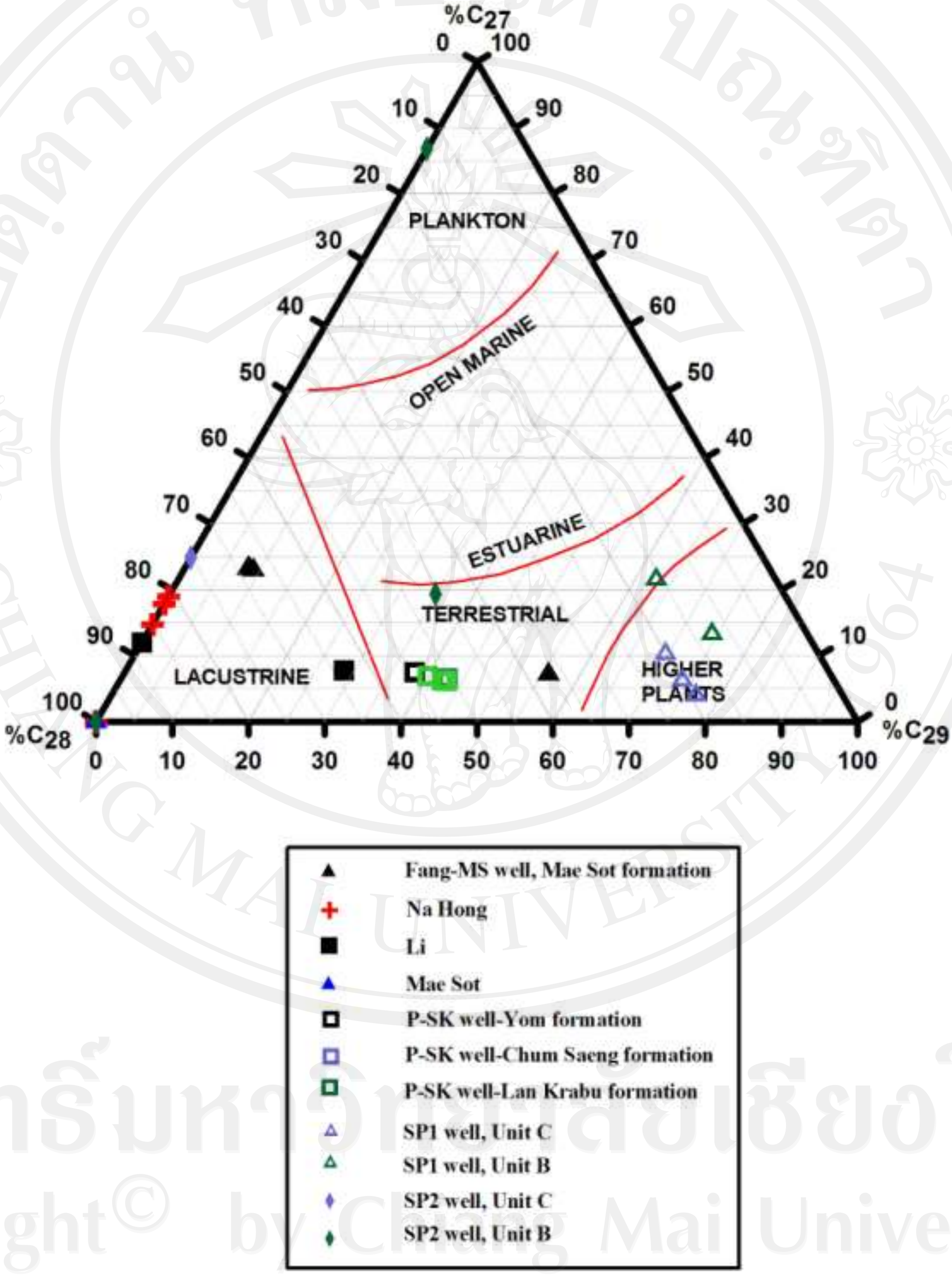


**Figure 5.3** Triangular diagram showing interpretation of environment from $C_{27}$, $C_{28}$ and $C_{29}$ regular steranes distribution (Shanmugam, 1985).

The most of sulphur content (TS) of Na Hong samples are low but two sample have elevated TS contents (~14-16 wt%) which relatively high TOC/TS ratios, generally ranging from 2 to 30. Nevertheless, the detected TOC/TS ratios in the samples from Na Hong could imply slightly or occasionally brackish conditions during deposition (Figure 5.4). The presence of framboidal pyrite indicates reducing conditions in the sediment.

The Pr/Ph ratios of Na Hong samples vary from 0.46 to 1.13 which also indicates anoxic to sub oxic condition and the Pristane/n$C_{17}$ versus Phytane/n$C_{18}$ plot (Figure 5.2) within the field reducing environment and indicated a high biodegradation effect and low in mature sample.

From the $C_{27}$, $C_{28}$ and $C_{29}$ regular sterane triangular diagram (Figure 5.3) of the samples indicated lake environment.

**Ban Pa Kha subbasin, Li basin**

The organic matter of the Li samples is dominated by liptinite with with only minor amounts of huminite. The liptinite consists mainly of lamalginite, *Botryococcus*-type telalginite, fluorescing AOM, liptodetrinite, sporinite and exsudatinite.

The oil shales are all of the lamosite type, but high concentrations of telalginite with *Botryococcus*-morphology could indicate intervals with torbanite (Hutton, 1987). The lamalginite of the Li oil shale is filamentous and is considered to originate from *Pediastrum* (Sherwood *et al.*, 1984; Cook and Sherwood, 1991). The *Botryococcus*-type telalginite indicates freshwater to brackish condition (Moldowan and Seifert, 1980; McKirdy *et al*., 1986).

The oil shales were deposited in open water lakes but the presence of terrestrial organic matter points to a consistent influx of higher land plant material, maybe due to nearby vegetated mire areas. This would be consistent with the associated coals that represent periods with extensive peat-forming mires. However, the high preservation (generally high TOC contents) indicates dominantly oxygen-lacking lake bottom conditions.

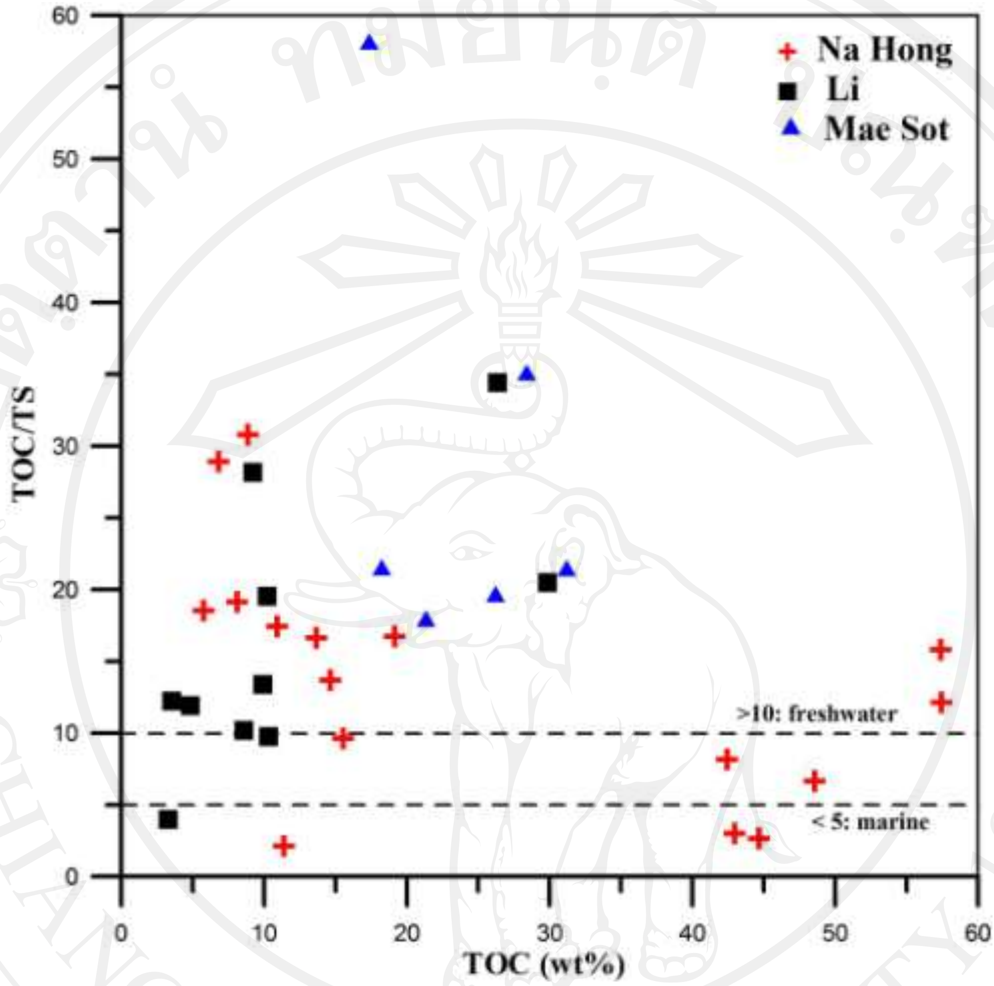


**Figure 5.4** TOC/TS versus TOC plot showing relatively high TOC/TS ratios of the samples from Na Hong, Li and Mae Sot basins (TOC/TS boundaries from Berner and Raiswell, 1984).

Most of the TS contents of the Li oil shales suggest fresh water; one sample from Li basin has elevated TS content indicating saline influence on the lake. The overall organic matter composition for the sample corresponds to type I kerogen with a subordinated proportion of type II and III kerogens which is commonly associated with coals and fluvial deposits (Carroll and Bohacs, 2001) or forest swamp environment (Ratanasthien *et al*., 1999).

The sulphur content (TS) of Li samples is between 0.33 and 1.46 wt%, with relatively high TOC/TS ratios, generally ranging from 4 to 35. The detected TOC/TS ratios in the samples could imply slightly or occasionally brackish conditions during deposition (Figure 5.4). The presence of framboidal pyrite indicates reducing conditions in the sediment. The Pr/Ph ratios of Li samples vary from 1.66 to 1.71 indicates sub oxic condition. The Pristane/n$C_{17}$ versus Phytane/n$C_{18}$ plot (Figure 5.2) falls within the field oxidizing environment but close to reducing environment and indicated a high biodegradation effect and low in mature sample.

From the $C_{27}$, $C_{28}$ and $C_{29}$ regular steranes triangular diagram (Figure 5.3) of the sample, it indicated a lake environment.

**Mae Sot basin**

The organic matters of the samples from Mae Sot basin are dominated by liptinite with only minor amounts of huminite. The liptinite consists mainly of laminated lamalginite, fluorescing amorphous organic matter, telalginite, predominantly with morphology similar to the extant algae *Botryococcus* followed by liptodetrinite. The lamalginite of the oil shales has primarily been assigned to the green algae *Pediastrum* (Sherwood *et al*., 1984), but microbial mats of cyanobacteria (blue-green algae) may likewise be a source (Schieber, 1999). According to the oil shale classification of Hutton (1987), the oil shales are of the lamosite type.

The Mae Sot oil shales are interpreted to have formed in freshwater to brackish lakes, and such depositional conditions are corroborated by presence of *Botryococcus*-type telalginite and the minor proportions of TS values and framboidal pyrite recorded in the shales. Sherwood *et al*. (1984) suggested that the water level was highly variable, whilst Gibling (1988) proposed oil shale deposition in a shallow to moderate-depth lake. The structureless, compact fluorescing AOM and the fluorescing AOM in the samples may appear to be more structured, which could be caused by a restricted reworking of the organic matter. However, the high preservation (generally high TOC contents) indicates dominantly oxygen-deficient lake bottom conditions. The very high TOC contents (~20 wt%), dominance of Type I kerogen (lamalginite +fluorescing AOM) and high HI values of 679 to 831 mg HC/g TOC correspond to the lacustrine algal organic characteristic of lake basins (Petersen *et al.*, 2006).

The sulphur content (TS) is usually low and vary between 0.30 and 1.46 wt%, with relatively high TOC/TS ratios, generally ranging from 18 - 58. The detected TOC/TS ratios in the Mae Sot samples could imply fresh water environment (Figure 5.4). Morever, the presence of framboidal pyrite indicates reducing conditions in the sediment. The Pr/Ph ratio varies from 0.46 to 0.55 which also indicates anoxic condition. The Pristane/n$C_{17}$ versus Phytane/n$C_{18}$ plot (Figure 5.2) falls within the field of reducing environment and indicated a high biodegradation effect and low in mature sample.

From the $C_{27}$, $C_{28}$ and $C_{29}$ regular sterane triangular diagram (Figure 5.3) of the samples, it also indicates a lacustrine environment.

**P-SK well, Phitsanulok basin**

The organic matter composition of the P-SK well samples shows primarily composed of liptinite in the form of exsudatinite and fluorescing AOM, liptodetrinite, laminated lamalginite, *Botryococcus*-type telalginite, resinite and followed by sporinite. Huminite is also present.

The lamalginite is considered to originate from *Pediastrum* (Sherwood *et al*., 1984; Cook and Sherwood, 1991). In contrast to the structureless, compact fluorescing AOM in the samples, the fluorescing AOM in the other oil shales may appear to be more structured, which could be caused by a restricted reworking of the organic matter.

The overall organic matter composition for the sample corresponds to type I kerogen with a subordinated proportion of type II and III kerogens. Small amounts of framboidal pyrite can be found in all samples. Such an organic matter composition is similar to the organic matter in freshwater (to slightly brackish) lacustrine mudstones (and oil shales) in other rift-basins onshore Thailand (Sherwood *et al*., 1984; Cook and Sherwood, 1991; Ratanasthien *et al*., 1999; Petersen *et al*., 2006).

The sulphur content (TS) is usually low and vary between 0.19 and 0.85 wt%, with relatively medium TOC/TS ratios, generally ranging from ~1.5–11.85. The detected TOC/TS ratios in well P-SK could imply slightly or occasionally brackish conditions during deposition (Figure 5.5). It can be interpreted that Lan Krabu Formation is less salinity than Chum Saeng, Pratu Tao and Yom formations. The presence of framboidal pyrite indicates reducing conditions in the sediment. The Pr/Ph ratios vary from 0.85 to 1.63 which also indicates sub-oxic condition and the Pristane/n$C_{17}$ versus Phytane/n$C_{18}$ plot (Figure 5.2) falls within the field oxidizing environment but close to the field reducing environment and indicated a low biodegradation effect and high in mature sample.

The $C_{27}$, $C_{28}$ and $C_{29}$ regular steranes triangular diagram (Figure 5.3) of the samples indicate terrestrial environment but close to lacustrine environment. The observed orange and brownish fluorescence colours may further suggest some degree of oxidation of the organic matter.

**SP1 and SP2 wells, Suphanburi basin**

The organic matter of the well SP1 samples is dominated by liptinite with only minor amounts of huminite (6.3 to 14.8 %) derived from higher land plants. The organic matter consists mainly of laminated lamalginite, liptodetrinite, fluorescing amorphous organic matter, exsudatinite, telalginite, predominantly with morphology similar to the extant algae *Botryococcus*, resinite followed by sporinite. The lamalginite is filamentous and is considered to originate from *Pediastrum* (Sherwood *et al*., 1984; Cook and Sherwood, 1991).

The organic matter of the well SP2 samples is dominated by liptinite with only minor amounts of huminite (9.1 to 15.7 %) derived from higher land plants. The organic matter consists mainly of laminated lamalginite, liptodetrinite, telalginite, predominantly with morphology similar to the extant algae *Botryococcus*, fluorescing amorphous organic matter, exsudatinite, resinite followed by sporinite and cutinite.

The overall organic matter composition for the SP1 and SP2 samples corresponds to type I kerogen with a subordinated proportion of type II and III

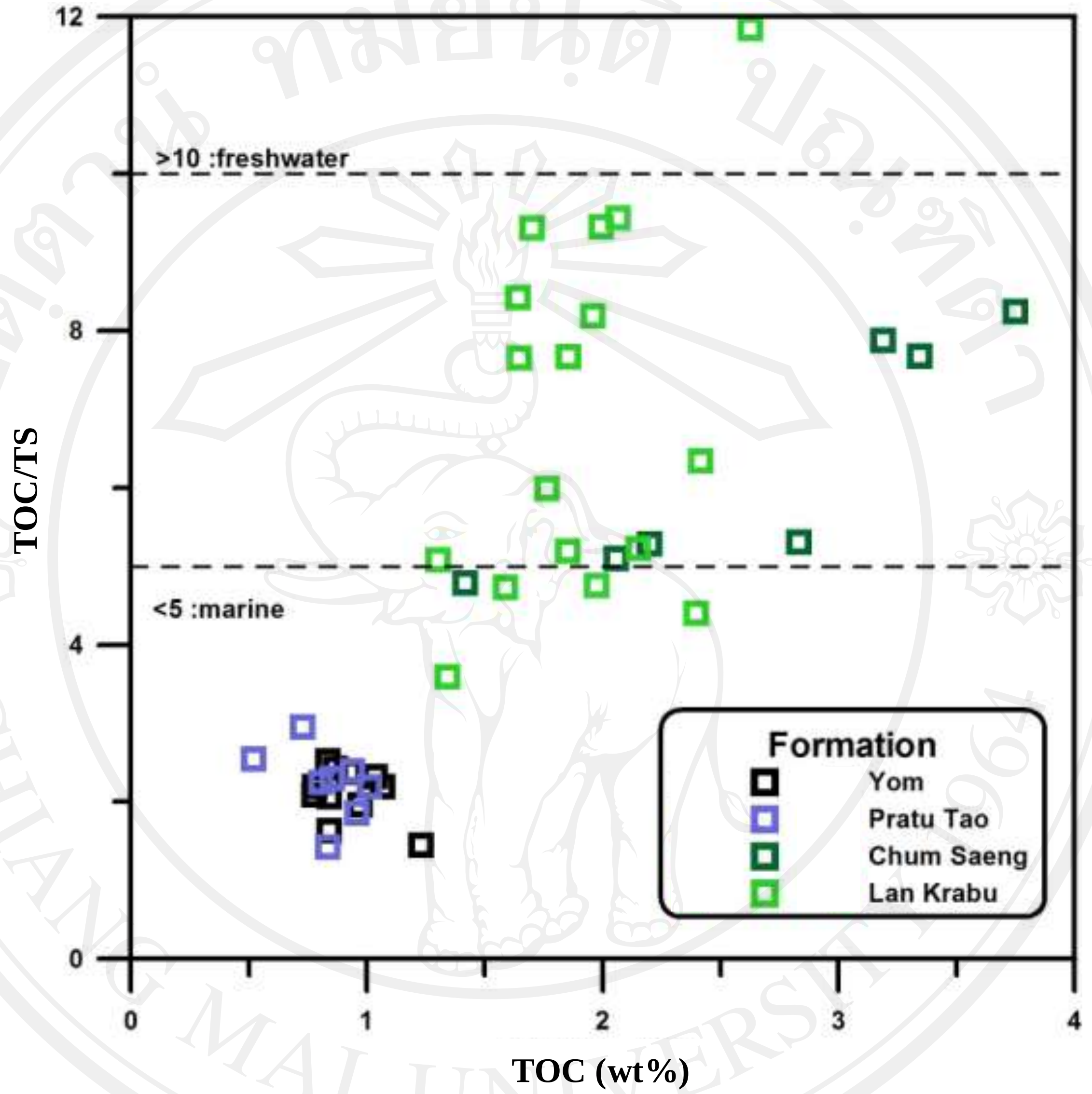


**Figure 5.5** TOC/TS versus TOC plot showing relatively high TOC/TS ratios of the samples from P-SK well. (TOC/TS boundaries from Berner and Raiswell, 1984)

kerogens. Small amounts of framboidal pyrite can be found in all samples. Such an organic matter composition is similar to the organic matter in freshwater (to slightly brackish) lacustrine mudstones (and oil shales) in other rift-basins onshore Thailand (Sherwood *et al*., 1984; Cook and Sherwood, 1991; Ratanasthien *et al*., 1999; Petersen *et al*., 2006).

The sulphur content (TS) is usually low and vary between 0.02 and 1.47 wt%, in well SP1 and between 0.03 and 1.11 wt% in well SP2. The TOC/TS ratios, are generally ranging from 0.52 to 11.62 in well SP1 and 0.20 to 10.29 in well SP2. The detected TOC/TS ratios in wells SP1 and SP2 could imply slightly or occasionally brackish conditions during deposition (Figure 5.6). The plot can interpret that condition of deposition of Units A and D have high salinity than Units B and C. Brackish conditions could further explain the minor amounts of framboidal pyrite observed in the samples. The presence of framboidal pyrite indicates reducing conditions in the sediment.

The Pr/Ph ratios vary from 0.93 to 3.94 for SP1 well which indicates sub-oxic condition and the Pristane/$nC_{17}$ versus Phytane/$nC_{18}$ plot (Figure 5.2) falls within the field of oxidizing environment. The maturity of unit C of SP1 well is lower than unit B. The Pr/Ph ratios vary from 0.70 to 2.56 for SP2 well which also indicate sub-oxic condition and the Pristane/$nC_{17}$ versus Phytane/$nC_{18}$ plot (Figure 5.2) fall within the field of oxidizing environment. The maturity of unit C of SP2 well is lower than unit B.

The sterane triangular diagram of the samples from SP1 and SP2 wells (Figure 5.3) are also confirmed imply slightly or occasionally brackish conditions during deposition. The upper part of SP1 and SP2 wells compared of rock which associated with carbonate, therefore the depositional environment of Suphanburi basin could be affected by high salinity water.

## 5.2 Source rock quality and petroleum generation

The total organic carbon (TOC, wt%), the $S_1$ and $S_2$ (mg HC/g rock), Hydrogen Index, $T_{max}$ derived from Rock-Eval pyrolysis and EOM were employed to characterize the source rock quality and petroleum generation.

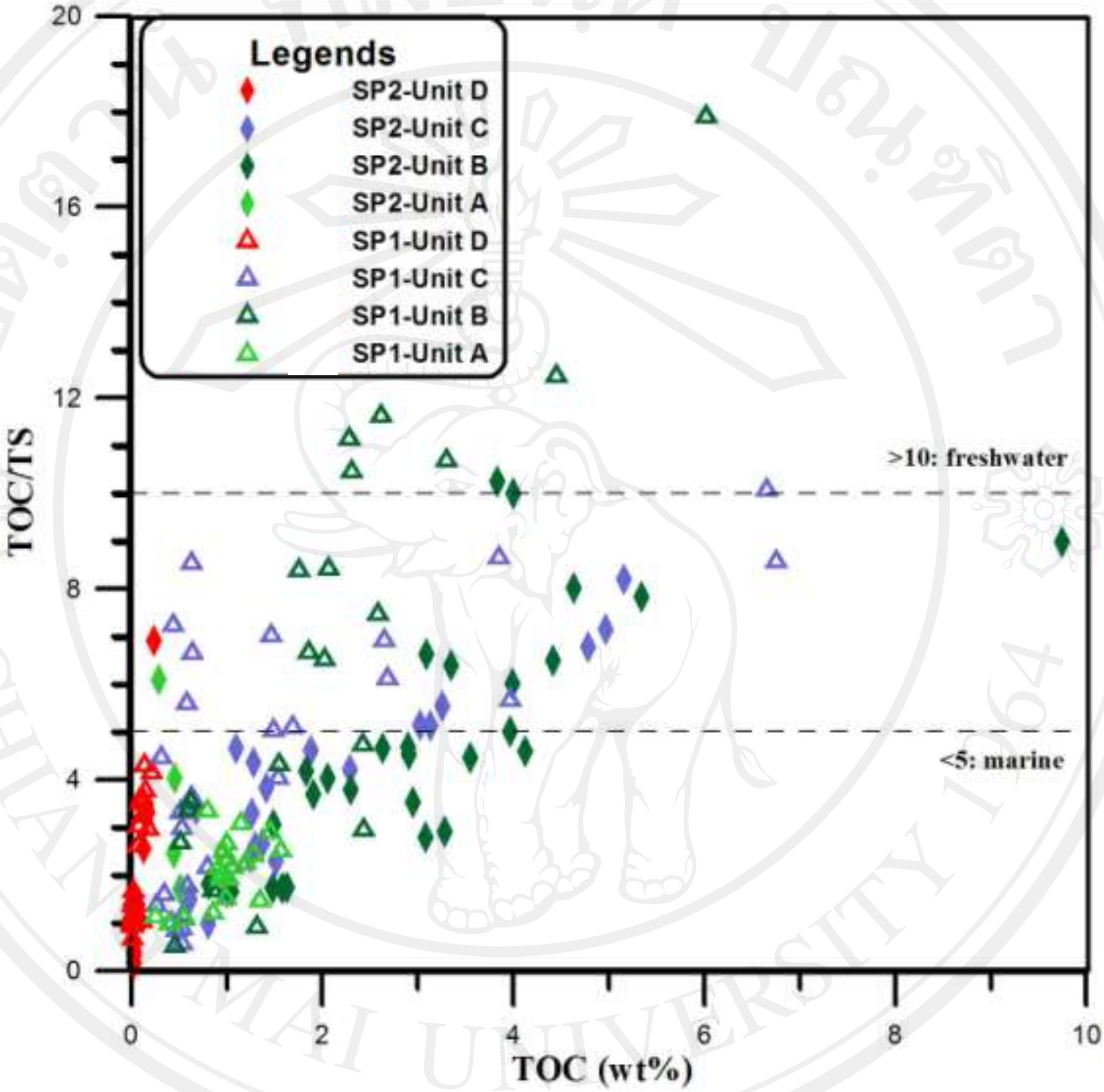


**Figure 5.6** TOC/TS versus TOC plot showing relatively high TOC/TS ratios of the samples from SP1 and SP2 well (TOC/TS boundaries from Berner and Raiswell, 1984).

**Fang basin**

The results of screening data can be interpreted that the samples from Fang-MS well were fair to good petroleum source rocks. The source rock is as types II and III kerogens and can generate mixed oil/gas and oil potential The best petroleum source rocks of Fang-MS well from depth between 874.78 and 1,002.79 m which TOC content higher 1.5 wt%, $S_2$ value higher than 4 mg HC/ g rock, HI value 291 to 428 mg HC/ g TOC.

The best petroleum source rocks of Fang-MS well are from depth between 874 and 1,002 m and 1054 and 1066 m with TOC content higher than 1.5 wt%, $S_2$ value higher than 4 mg HC/g rock, HI value 291 to 428 mg HC/g TOC. They are of fair to good source rock and can generate gas/oil and oil. According to $T_{max}$ and PI, maturity of samples from Fang-MS well was immature

The plot of $S_2$ yield against TOC of these samples (Figure 5.7 A) also indicates as fair to good petroleum source rock. The plot of HI against $T_{max}$ (Figure 5.7 B) indicates types II and III kerogens and suggests that they can generate mixed oil/gas and oil potential.

**Na Hong basin**

The results of screening data can be interpreted that the samples from Na Hong samples were classified as good to excellent petroleum source rocks. The source rock is as types II and III kerogens and suggests they can generate mixed oil/gas and oil. The best petroleum source rocks of Na Hong sample is coaly mudstone which TOC content higher 40 wt%, $S_1$ value higher than 3 mg HC/ g rock, $S_2$ value higher than 100 mg HC/ g rock, HI value 275 to 414 mg HC/ g TOC.

The best petroleum source rocks of Na Hong sample is coaly mudstone which has TOC content higher 40 wt%, $S_1$ value higher than 3 mg HC/ g rock, $S_2$ value higher than 100 mg HC/g rock, HI value between 275 to 414 mg HC/g TOC. Thus, the Na Hong samples were classified as good to excellent petroleum source rocks. According to $T_{max}$ and PI, maturity of samples from Na Hong basin was immature

The $S_2$ yield against TOC cross plot (Figure 5.8 A) also indicated as good to excellent petroleum source rock. The HI against $T_{max}$ plot (Figure 5.8 B) indicated as types II and III kerogens and suggests they can generate mixed oil/gas and oil.

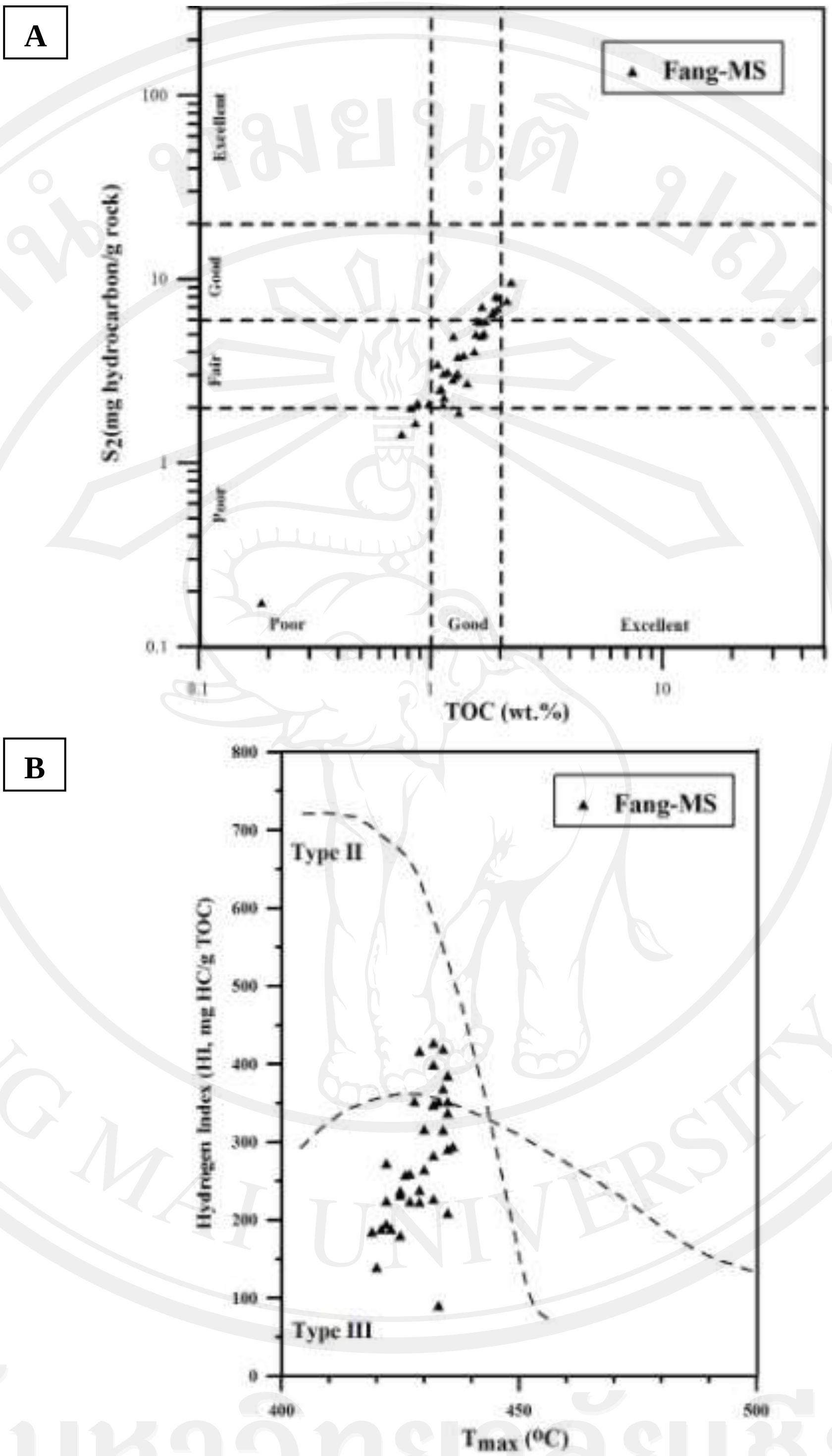


**Figure 5.7** (A) $S_2$ yields plot against the TOC content suggesting a fair to good source rock quality, $S_2$ and TOC cut-off values based on Peters and Moldowan (1993); (B) Hydrogen Index versus $T_{max}$ plot. The kerogen of Fang-MS samples falls within the areas of Type II and III and possess a potential for mixed oil/gas and oil generation (graph after Tissot and Welte, 1978).

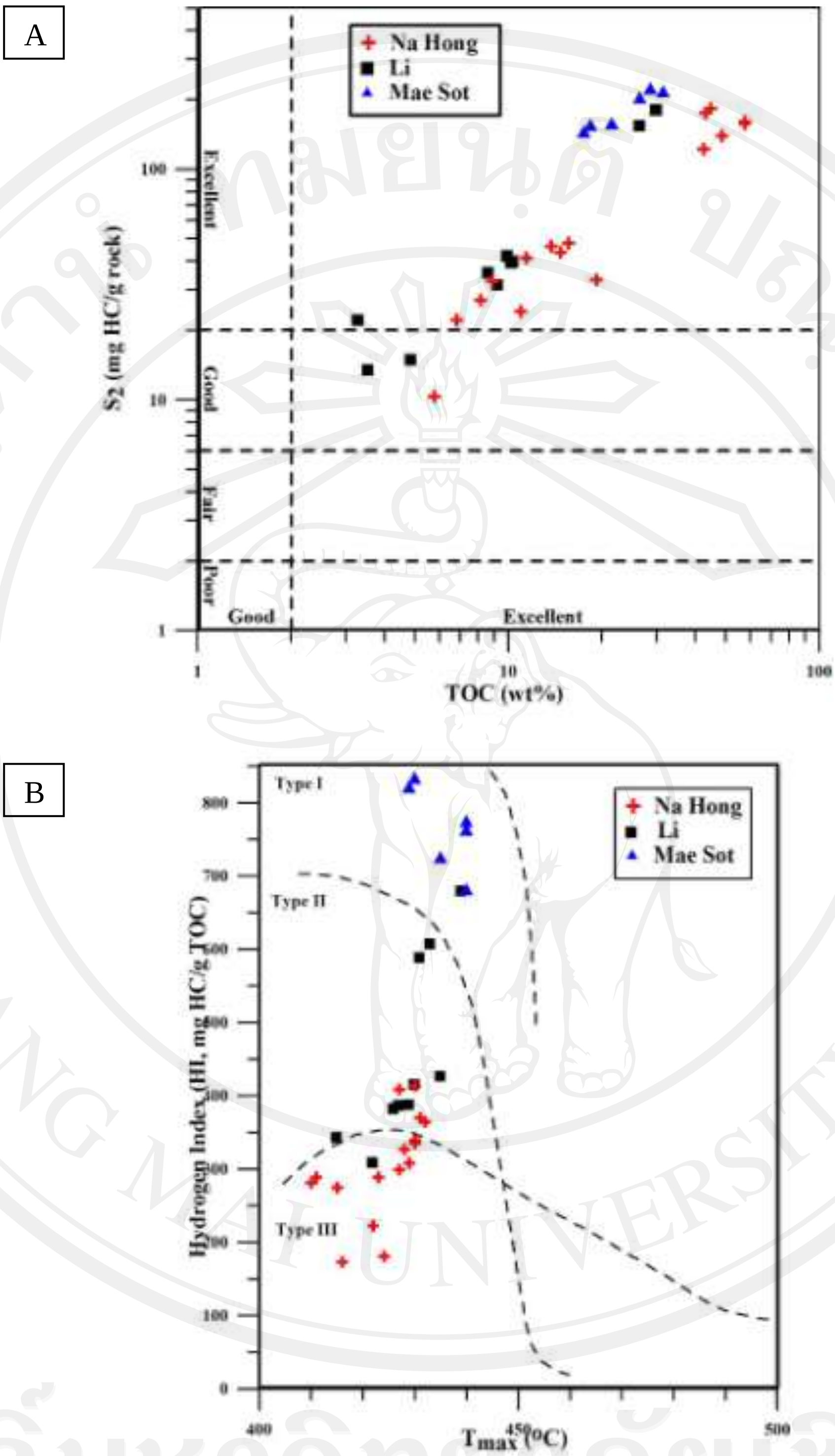


**Figure 5.8** (A) $S_2$ yields plot against the TOC content of Na Hong, Li and Mae Sot samples, $S_2$ and TOC cut-off values based on Peters and Moldowan (1993).; (B) Hydrogen Index versus $T_{max}$ plot of Na Hong, Li and Mae Sot samples (graph after Tissot and Welte, 1978).

**Ban Pa Kha subbasin, Li basin**

The results of screening data can be interpreted that the samples from Li samples were good to excellent petroleum source rocks. The source rock is as types I, II and III kerogens and suggests they can generate mixed oil/gas and oil. The best petroleum source rocks of Li is oil shale which TOC content higher 25 wt%, $S_1$ value higher than 2 mg HC/ g rock, $S_2$ value higher than 100 mg HC/ g rock, HI value 588 and 607 mg HC/ g TOC.

The best petroleum source rocks of Li is oil shale which has TOC content higher 25 wt%, $S_1$ value higher than 2 mg HC/g rock, $S_2$ value higher than 100 mg HC/ g rock, HI value 588 and 607 mg HC/g TOC. Thus, the Li samples were classified as good to excellent petroleum source rocks. According to $T_{max}$ and PI, maturity of samples from Li basin was immature The $S_2$ yield against TOC cross plot (Figure 5.8 A) also indicated as good to excellent source rock. The HI against $T_{max}$ plot (Figure 5.8 B) indicated as types I, II and III kerogen and can generate mixed oil/gas and oil potential.

**Mae Sot Basin**

The results of screening data can be interpreted that the samples from Mae Sot were very good to excellent petroleum source rocks. The source rock is as type I kerogen and suggests they can generate oil. The best petroleum source rocks of Mae Sot is oil shale which TOC content higher 25 wt%, $S_1$ value higher than 3 mg HC/ g rock, $S_2$ value higher than 150 mg HC/ g rock, HI value 679 to 771 mg HC/ g TOC.

The best petroleum source rocks of Mae Sot is oil shale which TOC content higher 25 wt%, $S_1$ value higher than 3 mg HC/g rock, $S_2$ value higher than 150 mg HC/ g rock, HI value 679 to 771 mg HC/g TOC. Thus, the Mae Sot samples were classified as excellent petroleum source rocks. According to $T_{max}$ and PI, maturity of samples from Mae Sot basin was immature

The $S_2$ yield against TOC cross plot (Figure 5.8 A) also indicate an excellent petroleum source rock. The HI against $T_{max}$ plot (Figure 5.8 B) indicated as type I kerogens and can generate oil.

**P-SK well, Phitsanulok Basin**

The results of screening data can be interpreted that the samples from Yom formation were fair source rocks. The samples from Pruta Tao formation were poor to fair source rocks. The samples from Chum Saeng formation were good to very good source rocks. The samples from Lan Krabu formation were fair to very good rocks. The best petroleum source rock of P-SK well are at depths between 1,900 and 2,200 m which are in Chum Saeng formation and depths between 2,600 and 2,800 m which is in Lan Krabu formation. The source rocks are as type II kerogen and can generate oil potential for Chum Saeng formation and indicated as III kerogen and can generate mixed oil/gas potential for Lan Krabu, Pratu Tao and Yom formation. TOC content higher than 2 wt%, $S_1$ value higher than 2 mg HC/g rock, $S_2$ value higher than 10 mg HC/ g rock, HI value 324 to 523 mg HC/ g TOC.

The best petroleum source rock of P-SK well are at depths between 1,900 and 2,200 m which is in Chum Saeng Formation and depths between 2,600 and 2,800 m which is in Lan Krabu Formation. They can generate gas/oil and oil. According to $T_{max}$ data, maturity of samples from P-SK well was immature. On the other hand, it can be interpreted as mature from Production Index data. In this case, $T_{max}$ and Production Index will be not sufficient to interpret the maturity. Thus, other parameters will be used to interpret samples maturity.

The $S_2$ yield against TOC cross plot (Figure 5.9 A) indicate a fair petroleum source rocks for Yom and Pratu Tao formations and indicate a good petroleum source rocks for Chum Saeng and Lan Krabu formations. The HI against $T_{max}$ plot (Figure 5.9 B) indicate a type II kerogen which can generate oil for Chum Saeng Formation and indicate a III kerogen which has mixed oil/gas potential for Lan Krabu, Pratu Tao and Yom formations.

**SP1 and SP2 wells, Suphanburi Basin**

**SP1 well**

The results of screening content can be interpreted that the samples from Unit D were no potential source rocks. The samples from Unit C were fair to excellent potential source rocks. The samples of Unit B were fair to excellent potential source rocks. The samples of Unit A were fair to good potential petroleum source rocks. The

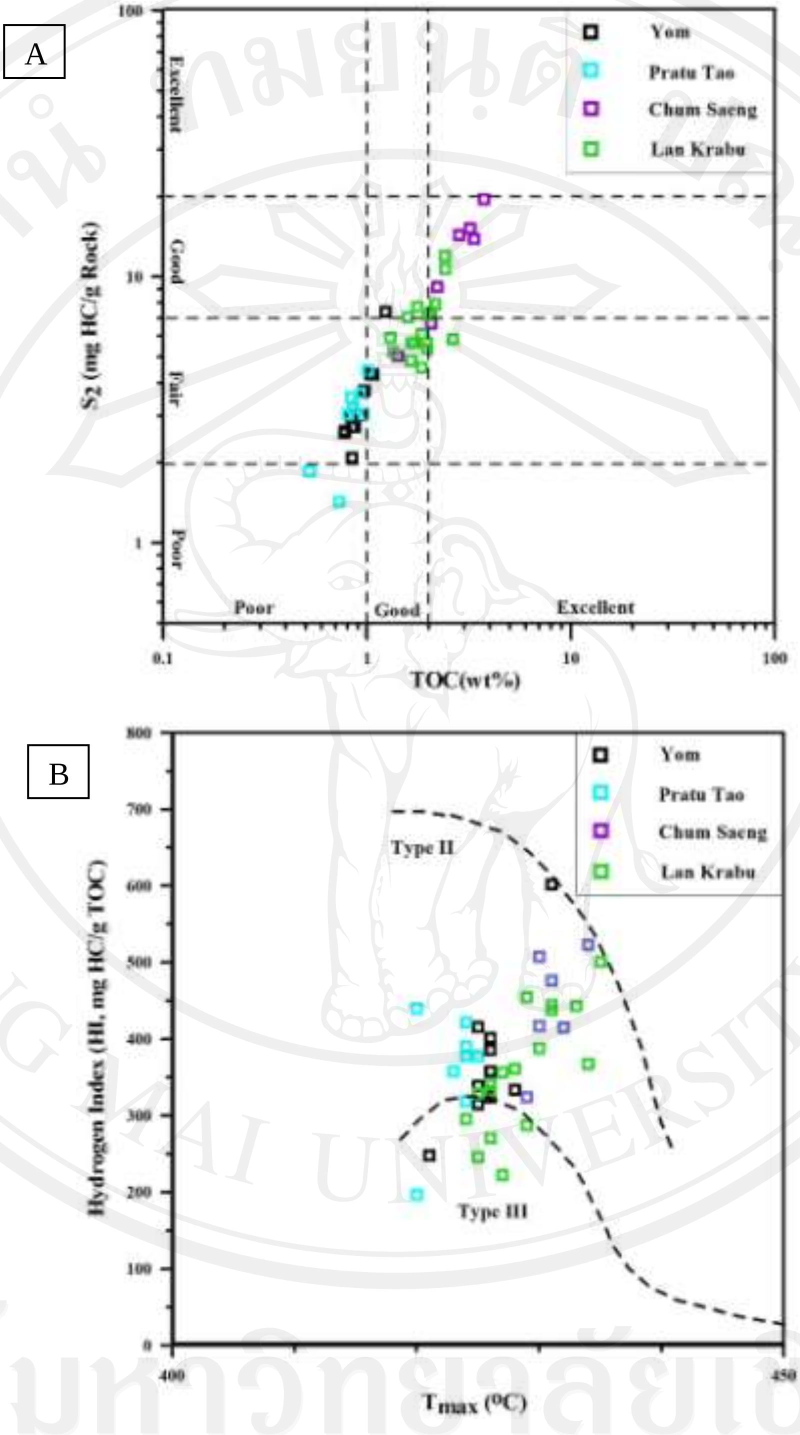


**Figure 5.9** (A) $S_2$ yields plot against the TOC content for P-SK samples suggesting a fair to excellent source rock quality, $S_2$ and TOC cut-off values based on Peters and Moldowan (1993); (B) Hydrocarbon Index versus $T_{max}$ plot. The kerogens of P-SK samples fall within the areas of Type II and III and possess a potential for mixed oil/gas and oil generation (graph after Tissot and Welte, 1978)

source rocks are as types II and III kerogen and can generate mixed oil/gas and oil potential for unit B and C and indicated as type III kerogen and can generate mixed oil/gas potential for unit A and D.

The best petroleum source rock of SP1 well from depths between 1,950 and 2,250 m which is unit B, have TOC content higher than 2 wt%, $S_2$ value higher than 5 mg HC/ g rock, HI value 247 to 390 mg HC/ g TOC.

The best petroleum source rock of SP1 well is depths between 1,950 and 2,250 m which is in unit B and can be generated gas/oil and oil. According to $T_{max}$ data, maturity of samples from SP1 well was immature to mature. Unit A, B and C can be interpreted as mature source rock. Almost of unit D can be interpreted as immature source rock. On the other hand, Production Index data can be interpreted as mature for upper of unit D. Almost of units A, B and C were interpreted as immature source rock. Unit D shows high values of PI because it may be getting migrated hydrocarbon.

The $S_2$ yield against TOC cross plot (Figure 5.10 A) indicated as no petroleum potential source rock for unit D, fair to good petroleum source rock for unit A and fair to excellent petroleum source rock for unit B and C. The HI against $T_{max}$ plot (Figure 5.10 B) indicated as types II and III kerogen and can generate mixed oil/gas and oil potential for unit B and C and indicated as type III kerogen and can generate mixed oil/gas potential for unit A and D.

**SP2 well**

The results of screening data can be interpreted that the samples from Unit D were no petroleum potential source rocks. The samples from Unit C were fair to excellent source rocks. The samples from unit B were fair to excellent petroleum source rocks. The samples from unit A were fair to good petroleum source rocks. The source rocks are as type II and III kerogen and can generate mixed oil/gas and oil potential for unit B and C. Unit A and D can generate only gas.

The best petroleum source rock of SP2 from depths between 1,200 and 1,250 m which is unit C and depths between 1,450 and 1,650 m which is unit B, TOC content higher than 2 wt%, $S_1$ value 0.17 to 1.17 mg HC/g rock, $S_2$ value higher than 10 mg HC/ g rock, HI value 446 to 675 mg HC/ g TOC.

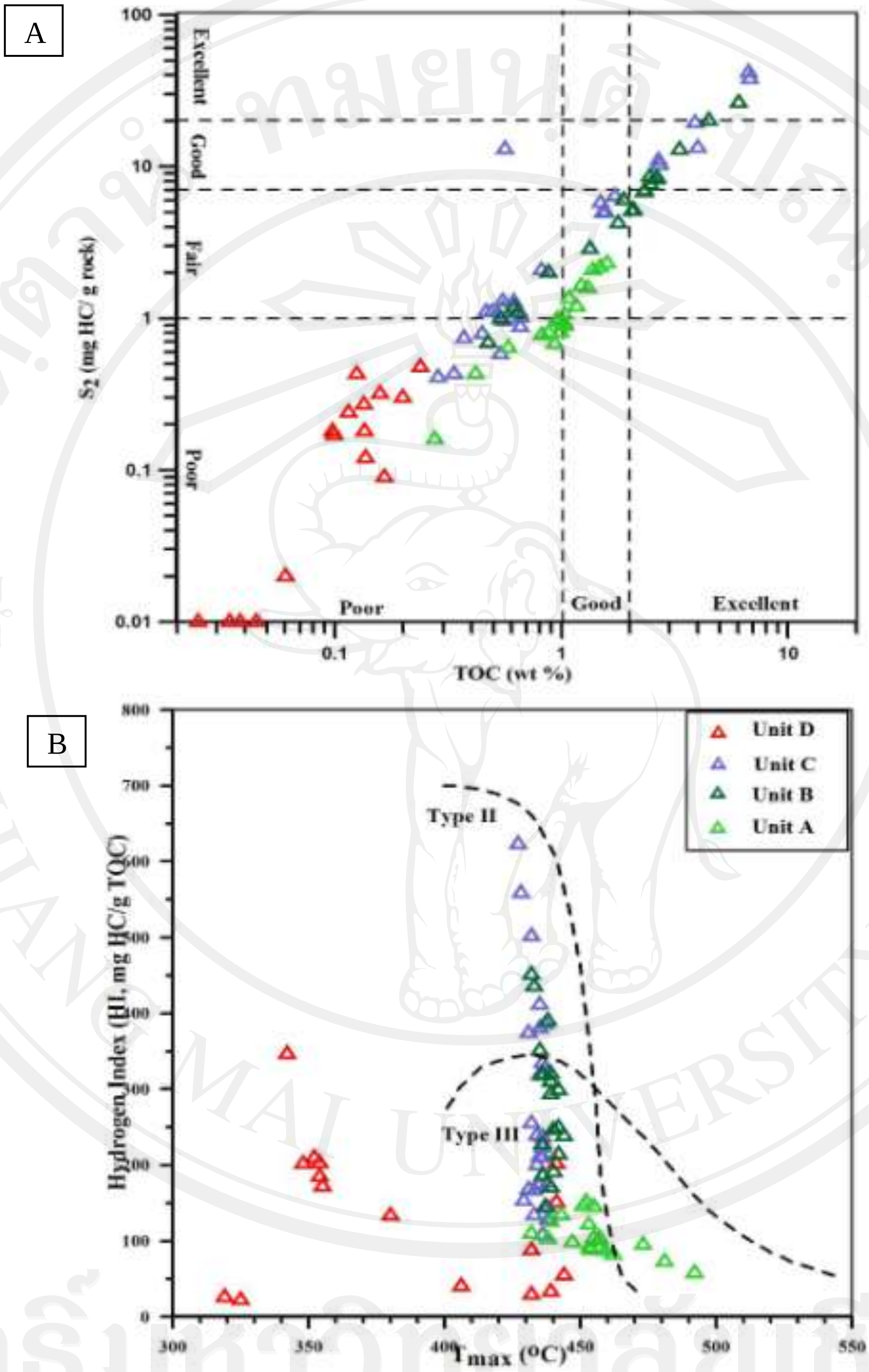


**Figure 5.10** (A) $S_2$ yields plot against the TOC content of samples from SP1 well suggesting a poor to excellent source rock quality, $S_2$ and TOC cut-off values based on Peters and Moldowan (1993); (B) Hydrogen Index versus $T_{max}$ plot of samples from SP1 well. The kerogen falls within the areas of Type II and III and possess a potential for mixed oil/gas and oil generation of SP1 samples (Tissot and Welte, 1978).

The best petroleum source rock of SP2 is depths between 1,200 and 1,250 m which is in unit C and depths between 1,450 and 1,650 m which is in unit B. According to $T_{max}$ data, maturity of all of samples from SP2 well was immature source rock. Production Index can be interpreted as mature for units D, C and upper of B. Lower of units B and A were interpreted as mature source rock.

The $S_2$ yield against TOC cross plot (Figure 5.11 A) indicated as poor petroleum source rock for unit D, fair to good petroleum source rock for unit A fair to excellent petroleum source rock for unit C and good to excellent petroleum source for unit B. The HI against $T_{max}$ plot (Figure 5.11 B) indicated as type II and III kerogen and can generate mixed oil/gas and oil potential for unit B and C. Unit A and D can generate only gas.

## 5.3 Source rock thermal maturity

The maximum temperature ($T_{max}$), Production Index (PI) derived from Rock-Eval pyrolysis, CPI, 22S/(22S+22R) homohopane ratio, Ts/(Ts+Tm) ratio, The $C_{29}$ 20S/(20S+20R) sterane ratio, $C_{29}$ ββ/ (ββ+αα) sterane ratio and vitrinite reflectance were employed to indicate the source rock thermal maturity.

### Fang basin

Most of the samples are Mae Sot Formation. $T_{max}$ values lower than 435$^o$C and Production Index (PI) values are generally significantly less than 0.1, indicating that they are immature source rock. In addition, CPI values are above 1.0 (range from 1.31-1.40), also indicating that they are immature source rock to close to top oil window.

The 22S/(22S+22R) homohopane ratio value is vary from 0.27–0.7. Samples have attained equilibrium values of about 0.47-0.60 at the depth around 1060 m the places the oil generation.  The Ts/(Ts+Tm) ratio value is vary from 0.25–0.36 (Figure 5.12). The $C_{29}$ 20S/(20S+20R) sterane ratio value is vary from 0.06 – 0.23. They are not reached the equilibrium values. The $C_{29}$ ββ/(ββ+αα) sterane ratio value is vary from 0.34-0.36 (Figure 5.13). Vitrinite reflectance values 0.38 to 0.66 %$R_o$ (Figure 5.14).

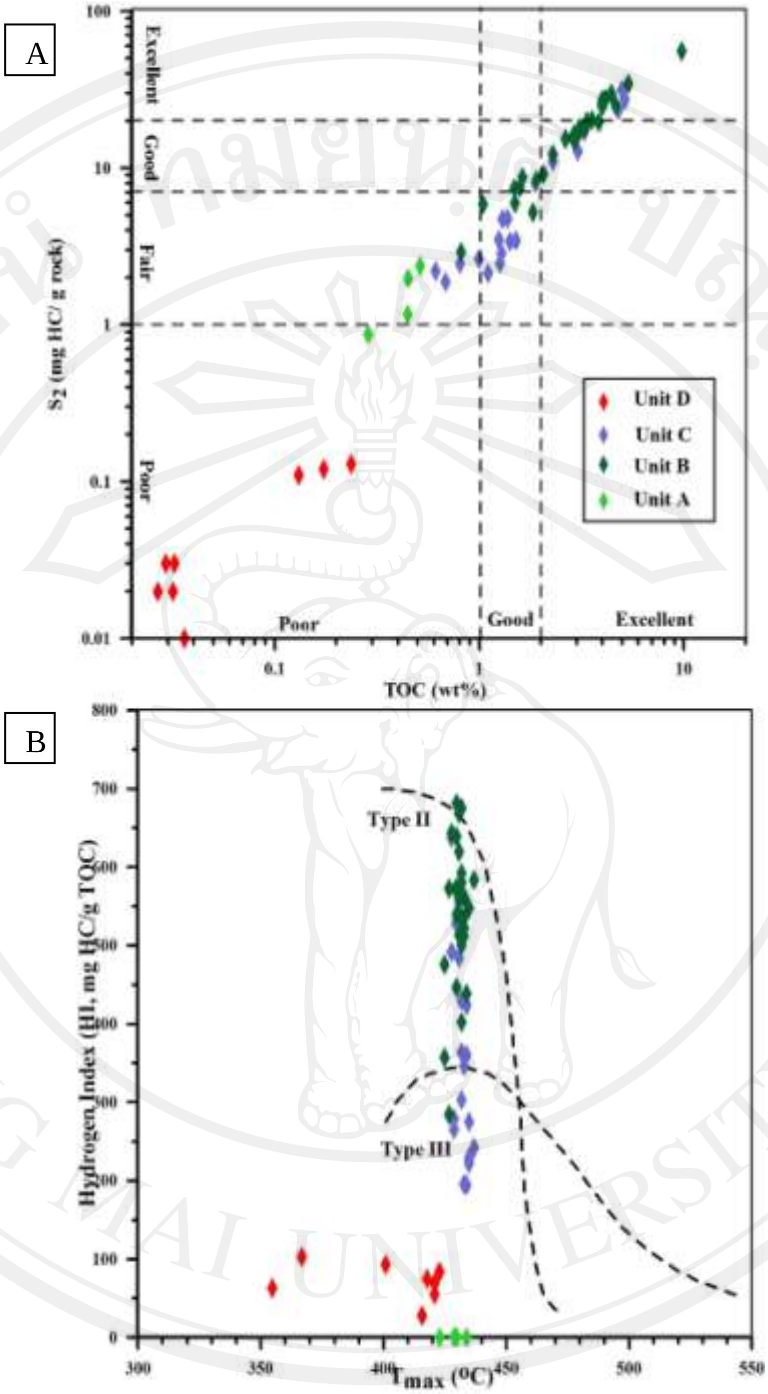


**Figure 5.11** (A) $S_2$ yields plot against the TOC content of samples of SP2 well suggesting a poor to excellent source rock quality, $S_2$ and TOC cut-off values based on Peters and Moldowan (1993); (B) Hydrogen Index versus $T_{max}$ plot of samples of SP2 well. The kerogens fall within the areas of Type II and III and possess a potential for mixed oil/gas and oil generation of SP2 samples (Tissot and Welte, 1978)

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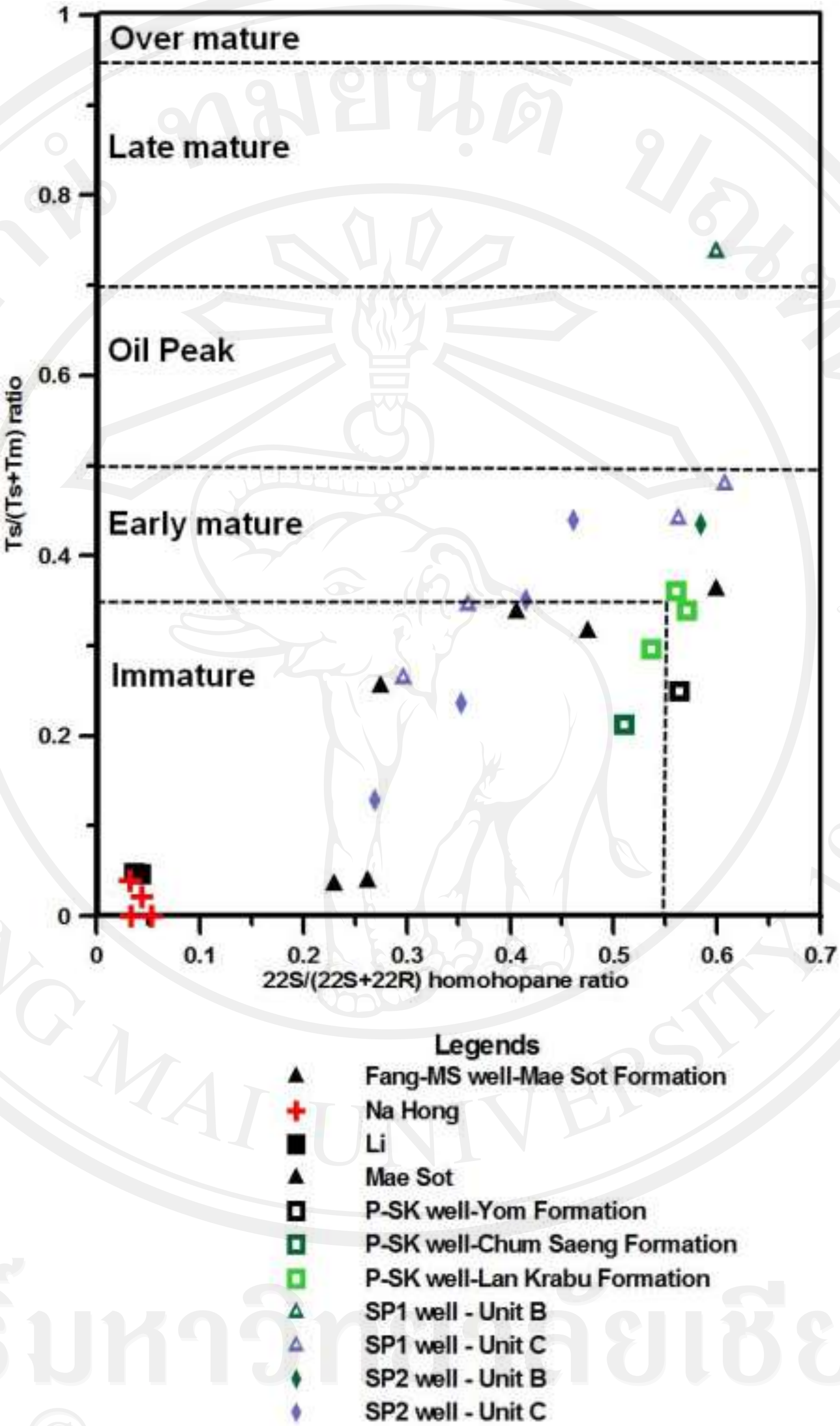


**Figure 5.12** $C_{31}$ 22S/(22S+22R) homohopane ratio versus $C_{27}$ Ts/(Ts+Tm) ratio plot suggesting source rock maturity (modified from Peters et al., 2005).

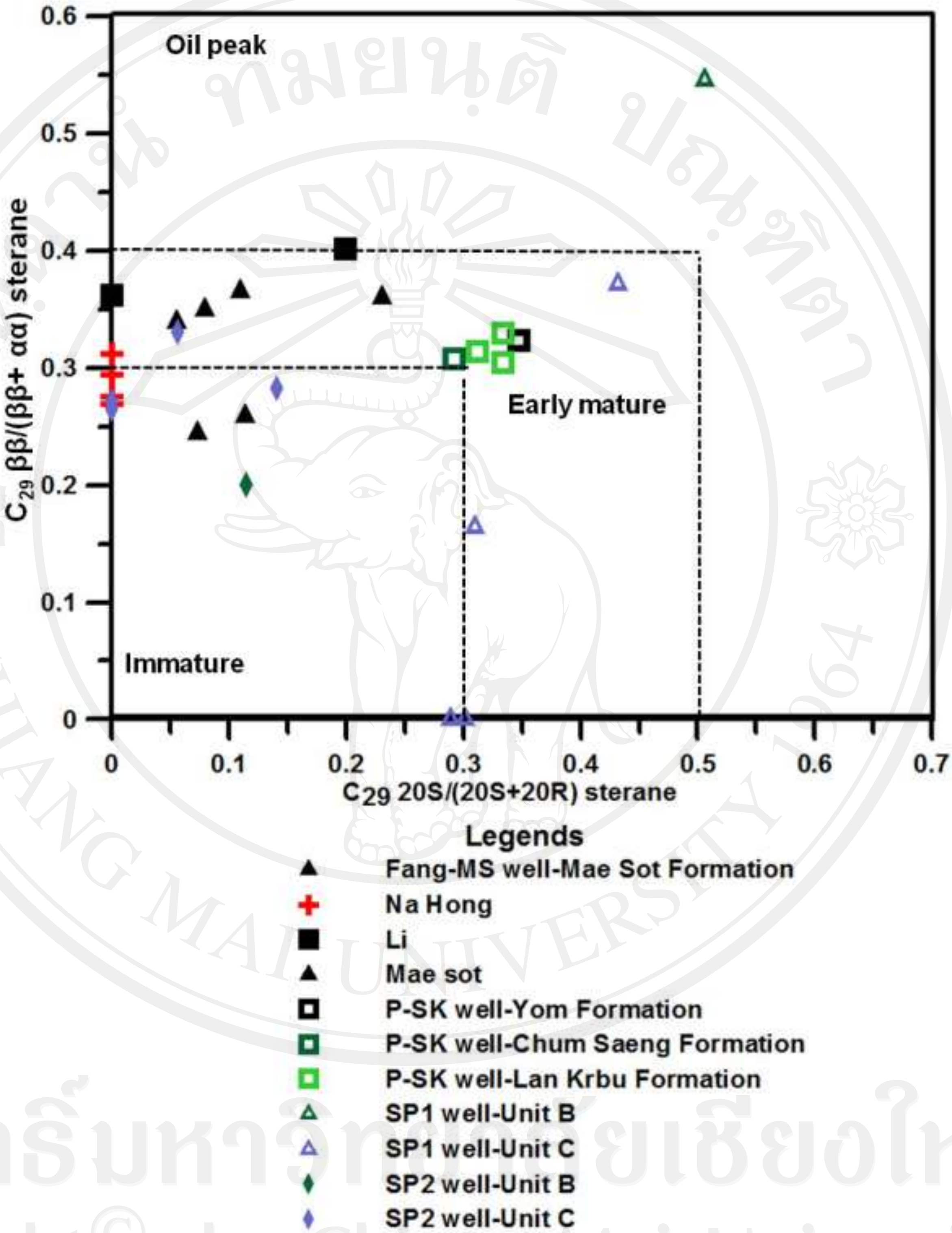


**Figure 5.13** $C_{29}$ 20S/(20S+20R) sterane ratio versus $C_{29}$ ββ/(ββ+αα) sterane ratio plot suggesting source rock maturity (modified from Peter *et al*., 2005).

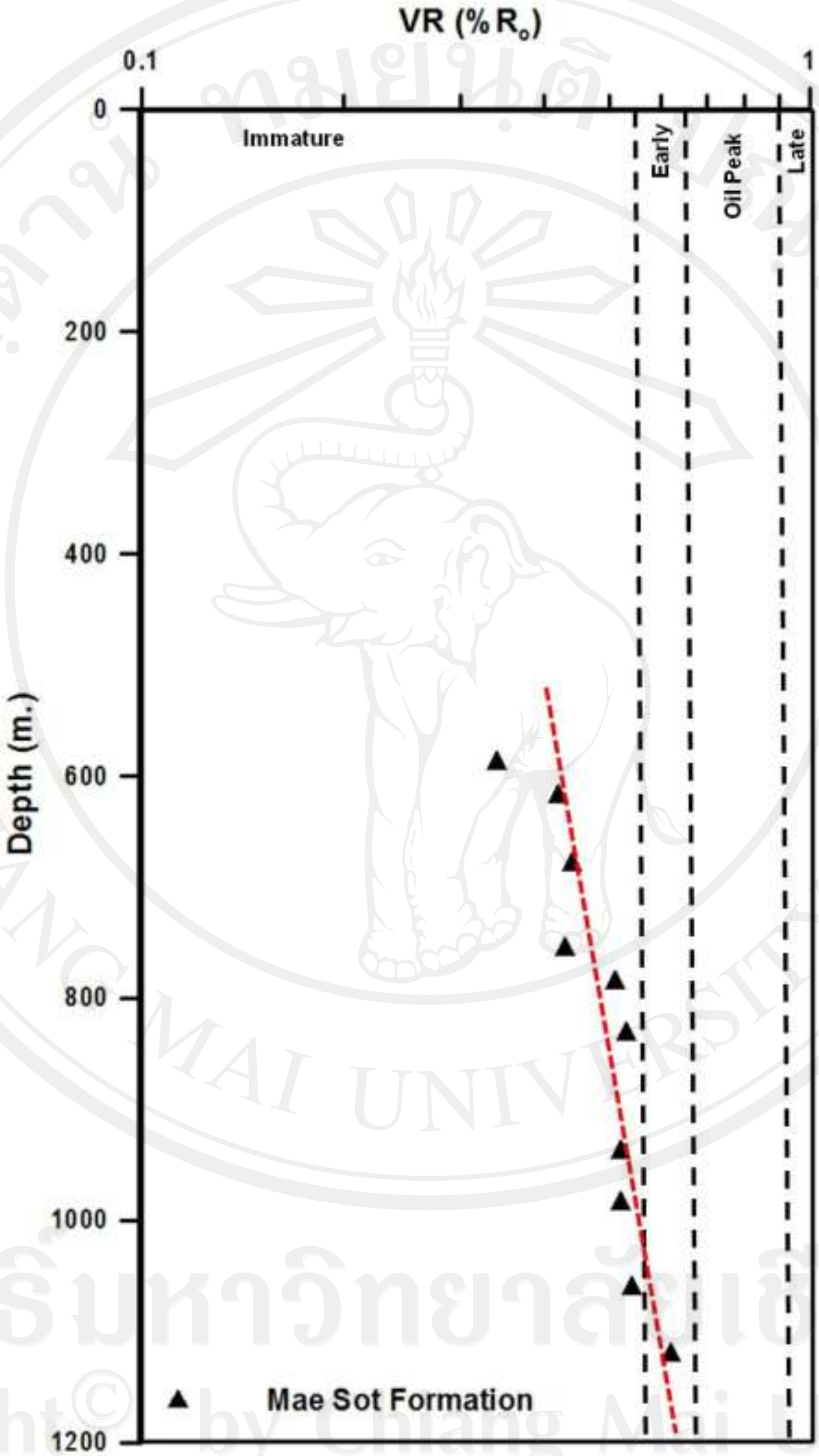


**Figure 5.14** Vitrinite reflectance versus depth plot suggesting source sock maturity os sample from Fang-MS well, Fang basin (modified from Peter *et al*., 2005)

Therefore, the samples from Mae Sot formation of Fang-MS well are thermally immature to early mature in terms of oil generation and thus the top of oil window is at depth around 1,100 m.

**Na Hong basin**

All of samples from Na Hong coalfield have $T_{max}$ value lower than 435$^{o}$C. Production Index (PI) values are generally significantly less than 0.1. In additional, CPI values are higher than 1.0 indicating immature source rock.

The 22S/(22S+22R) homohopane ratio is very low (less than 0.1) (Figure 5.12). The Ts/(Ts+Tm) ratio is very low. The $C_{29}$ 20S/(20S+20R) sterane and the $C_{29}$ ββ/ (ββ+αα) sterane ratio values is zero (Figure 5.13). Vitrinite reflectance (VR) values range from 0.40 to 0.49 %$R_o$. Therefore, the samples from Na Hong coalfield are thermally immature in terms of oil generation.

**Ban Pa Kha subbasin, Li basin**

All of samples have $T_{max}$ value lower than 435$^{o}$C. Production Index (PI) values generally significantly less than 0.1. CPI values higher than 1.0 indicating immature source rock.

The 22S/(22S+22R) homohopane ratio and the Ts/(Ts+Tm) ratio are very low (Figure 5.12). The $C_{29}$ 20S/(20S+20R) sterane ratio is very low. The $C_{29}$ ββ/ (ββ+αα) sterane ratio values is zero (Figure 5.13). Vitrinite reflectance (VR) values range from 0.36 to 0.40 %$R_o$. Therefore, the samples from Pa Kha coalfield, Li basin are thermally immature in terms of oil generation.

**Mae Sot basin**

The two-third of samples from Mae Sot basin have $T_{max}$ value higher than 435$^{o}$C. Production Index (PI) values generally significantly less than 0.1. CPI values higher than 1.0 indicating immature source rock.

The 22S/(22S+22R) homohopane ratio is around 0.2. The Ts/(Ts+Tm) ratio is very low (Figure 5.12). The $C_{29}$ 20S/(20S+20R) sterane ratio is very low. The $C_{29}$ ββ/ (ββ+αα) sterane ratio values is zero (Figure 5.13). Vitrinite reflectance (VR) values from 0.35 to 0.37 $\%R_o$. Therefore, the samples from Mae Sot are thus thermally immature in terms of oil generation.

**P-SK well, Phitsanulok basin**

All of samples have $T_{max}$ value higher than 435°C. All of samples has Production Index (PI) values higher than 0.1. CPI values close to 1.0, suggesting that they are thermally mature.

The 22S/(22S+22R) homohopane ratio is around 0.5. The Ts/(Ts+Tm) ratio is around 0.3 (Figure 5.12). The $C_{29}$ 20S/(20S+20R) sterane ratio is around 0.3. The $C_{29}$ ββ/ (ββ+αα) sterane ratio values is around 0.45 (Figure 5.13). Vitrinite reflectance (VR) values range from 0.40 to 0.66 $\%R_o$ (Figure 5.15).

Therefore, Yom and Pratu Tao formations are thermally mature for oil generation. Chum Saeng formation is immature to early mature for oil generation, while Lan Krabu formation is mature to oil peak in terms of oil generation. Thus, the top of oil window for P-SK well, Phitsanulok basin is around depth 3,000 m.

**SP1 and SP2 wells, Suphanburi basin**

**SP1 well**

Half of samples has $T_{max}$ value between 435 to 470°C. The one-third of samples has Production Index (PI) values higher than 0.1. CPI values decrease from 3.51 to 1.01.

The 22S/(22S+22R) ratio increase with depth from 0.30 to 0.60. The Ts/(Ts+Tm) ratio increase with depth from 0.26 to 0.74 (Figure 5.12). The $C_{29}$ 20S/(20S+20R) ratio increases with depth from zero to 0.51. The $C_{29}$ ββ/(ββ+αα) ratios are increase with depth from 0.30 to 0.55 (Figure 5.13). Vitrinite reflectance (VR) values range from 0.59 to 1.35 $\%R_o$ (Figure 5.16).

Therefore, maturity of Units C and B are early mature o peak oil generation. Maturity of Unit A is at peak oil to late mature of oil generation. Thus, the top of oil window of SP1 well is around depth 1,750 m.

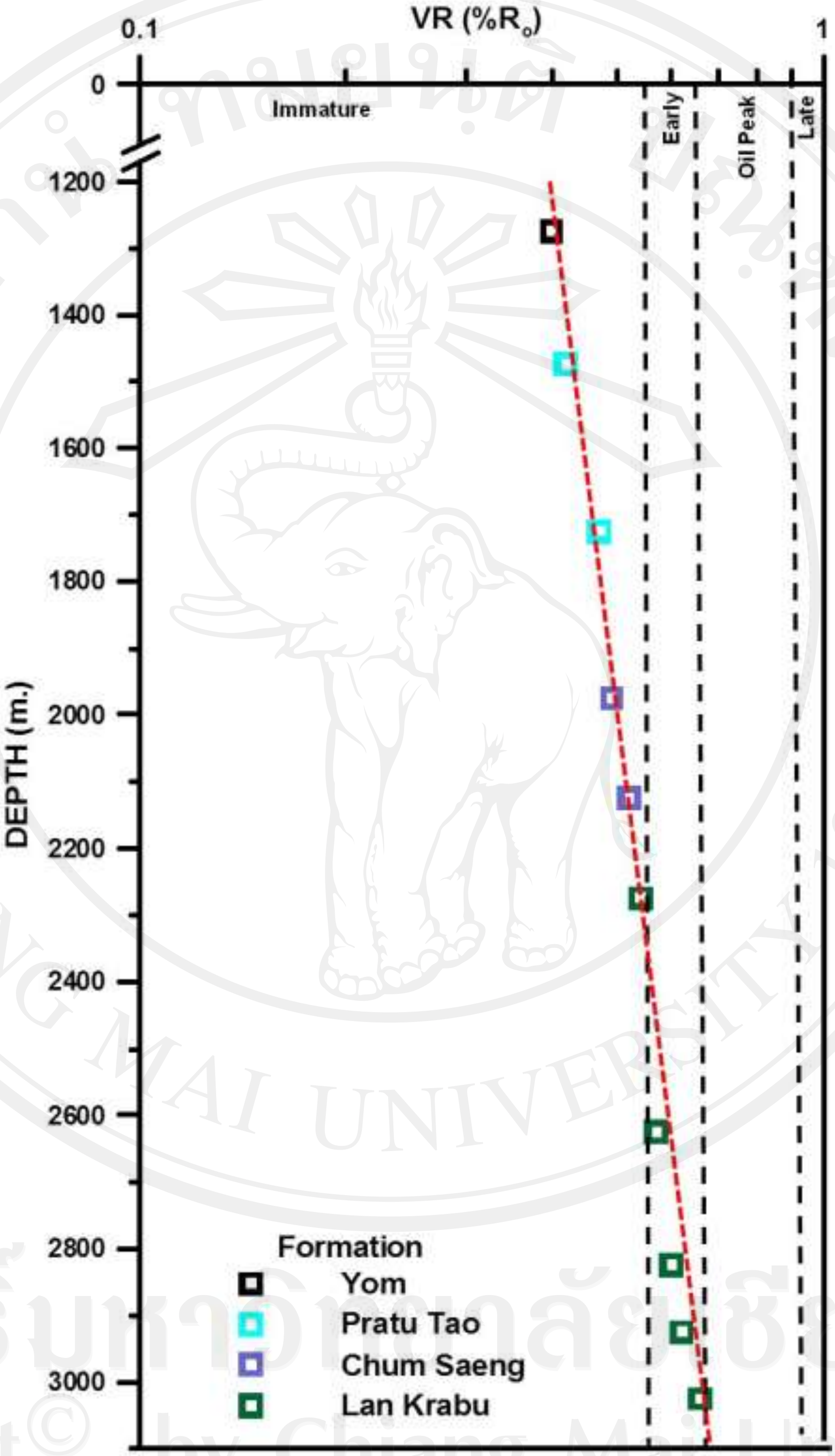


**Figure 5.15** Vitrinite reflectance versus depth plot suggesting source sock maturity os sample from P-SK well, Phitsanulok basin (modified from Peter *et al*., 2005)

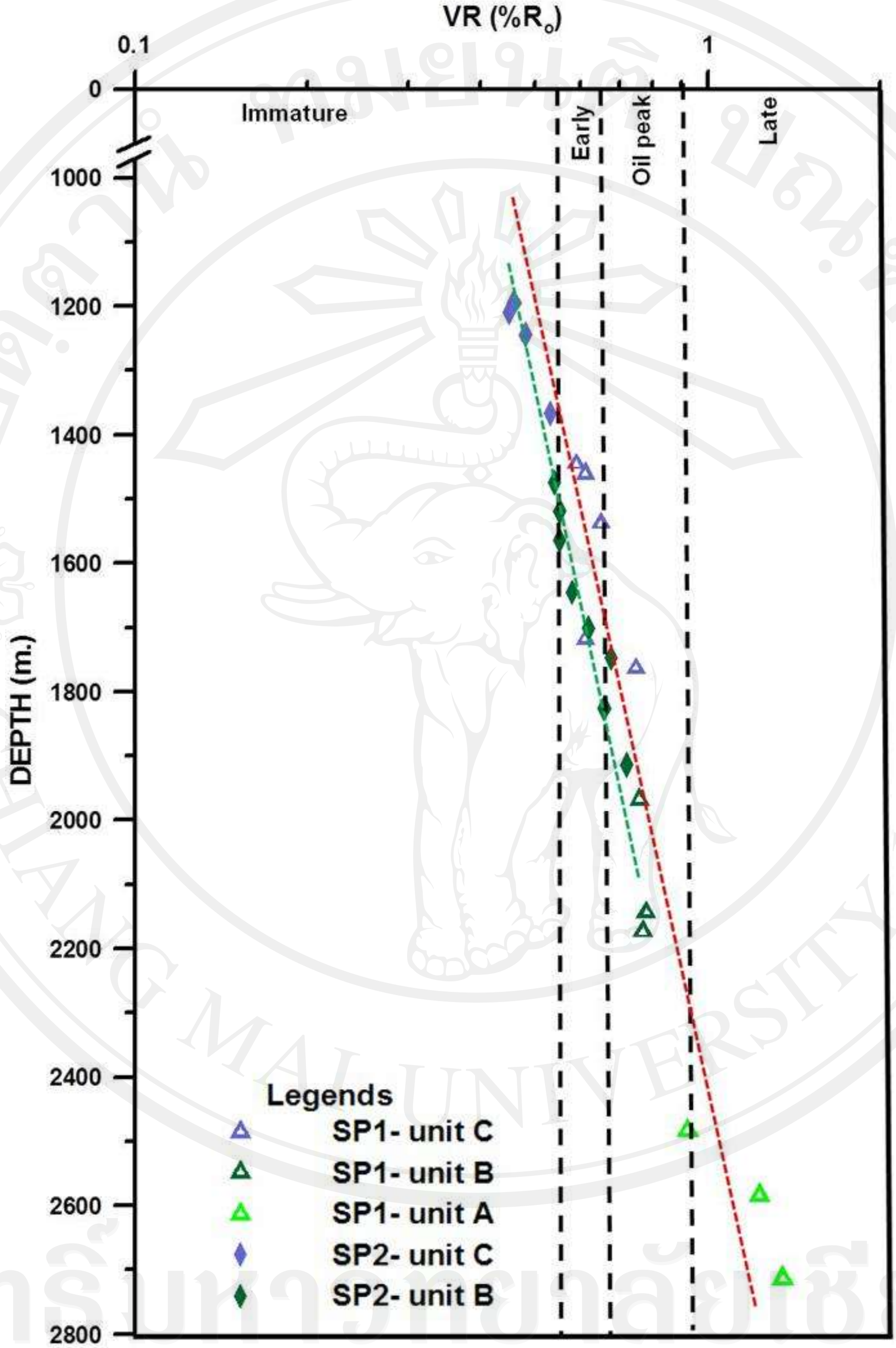


**Figure 5.16** Vitrinite reflectance versus depth plot suggesting source sock maturity os sample from SP1 and SP2 wells, Suphnburi basin (modified from Peter *et al*., 2005)

**SP2 well**

All samples have $T_{max}$ values higher than 435°C. Production Index (PI) values generally significantly less than 0.1. CPI value is higher than 1.0.

The 22S/(22S+22R) ratio is increased with depth from 0.27 to 0.58. The Ts/(Ts+Tm) ratio is increased with depth from 0.13 to 0.44 (Figure 5.12). The $C_{29}$ 20S/(20S+20R) ratio is around 0.1. The $C_{29}$ ββ/ (ββ+αα) ratio values is very low (Figure 5.13). Vitrinite reflectance (VR) values range from 0.46 to 0.72 %$R_o$ (Figure 5.16). Therefore, the samples from SP2 well are range from early mature to thermally mature in terms of oil generation.

Therefore, maturity of Unit C is immature to early mature and Unit B is early mature to peak oil generation. Thus, the top of oil window of SP2 well is around depth 1,800 m.