

# PETROLEUM SOURCE ROCK AND MIGRATION IN THE MERGUI BASIN, THE ANDAMAN SEA, THAILAND: PREDICTION FROM AN ORGANIC GEOCHEMISTRY STUDY USING THE PETROMOD PROGRAM

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*Received: October 22, 2013; Revised: March 03, 2014; Accepted: March 26, 2014*

## Abstract

The main objective of this research is to identify petroleum source rock and the petroleum migration path of the Mergui basin, Andaman Sea, Thailand. An assessment of the petroleum generation was performed by a geochemical analysis of the rock and running the basin modelling using commercial computer software named PetroMod, whilst the migration path was determined by the porosity of the Ranong Formation and the thermal maturity of the sediments. The results of the study indicated that source rocks were present in the Yala, Kantang, and Trang Formations but were immature throughout the basin. Only the Yala Formation could be properly exploited to generate petroleum. The petroleum source rock of the Yala Formation is marine shale which has total organic carbon values ranging between 0.5 and 1.5%. Its organic matter is Type III terrestrial, which represents a gas prone kerogen, whilst its thermal maturity has a vitrinite reflectance ( $R_o$ ) range between 0.6 and 1.0; the  $T_{max}$  of the Yala formation is in the range between 430°C to nearly 450°C and its production index ranges between 0.1 and 0.4. The oil window lies around 2100 m, 3000 m, and 4500 m in the north Mergui basin, main Mergui basin, and Andaman slope areas, respectively. The Oligocene to early Miocene period Yala Formation is mature over most of the basin. From the results of the potential of the reservoir in the Ranong Formation with its thermal maturity, the geothermal gradient in the basin indicated that the hydrocarbons' expulsion and migration were believed to have taken place mainly beginning around the middle Miocene period and still continue today. Hydrocarbons are primarily being generated and are migrating from the deep east Mergui, west Mergui, and Ranong troughs.

**Keywords:** Petroleum source rock, migration pathway, PetroMod, Mergui basin, the Andaman Sea

## Introduction

Tertiary basins are the main target of petroleum exploration and production in Thailand. The Mergui basin is one of the important tertiary basins located in the Andaman Sea, offshore from western Thailand. Many studies have reported that the Mergui basin is comprised

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of good petroleum source rocks and suitable petroleum traps. Unfortunately, exploration in the Mergui basin has so far been unsuccessful as 10 wells which have been drilled within block No. W-9 have shown only minor traces of gas which were observed in the Trang-1 and Mergui-1 wells (Polachan and Racey, 1994). Much research concluded that this area is at an immature stage presenting a trace of oil/gas. However, petroleum source rock identification is an important task in evaluating a petroleum-bearing basin since it is directly related to its petroleum resource potential and exploration directions. Organic geochemistry analysis is commonly used for oil/gas-source correlation. Previous works on geological history, tectonic evolution, general stratigraphy, and subsurface geology in this area were reviewed in this study in order to predict a possible petroleum migration pathway and traps. The study area was located between UTM 690000 and 1078786 North and between 120000 and 411636 East in zone 47 which covers approximately 50000 square kilometers (Figure 1). The generalized stratigraphy of the Mergui basin and the stratigraphic correlation to the North Sumatra basin is depicted in Figure 2.

## Materials and Methods

### Materials

The required data, including geochemical, petrophysical, and geophysical data of 18 wells drilled in the study area (Figure 1) were collected and prepared to serve the objective of the study. All of the required data for this assessment were compiled, reviewed, summarized, and documented from the relevant literature. These data were authorized and provided by the Department of Mineral Fuels, Ministry of Energy.

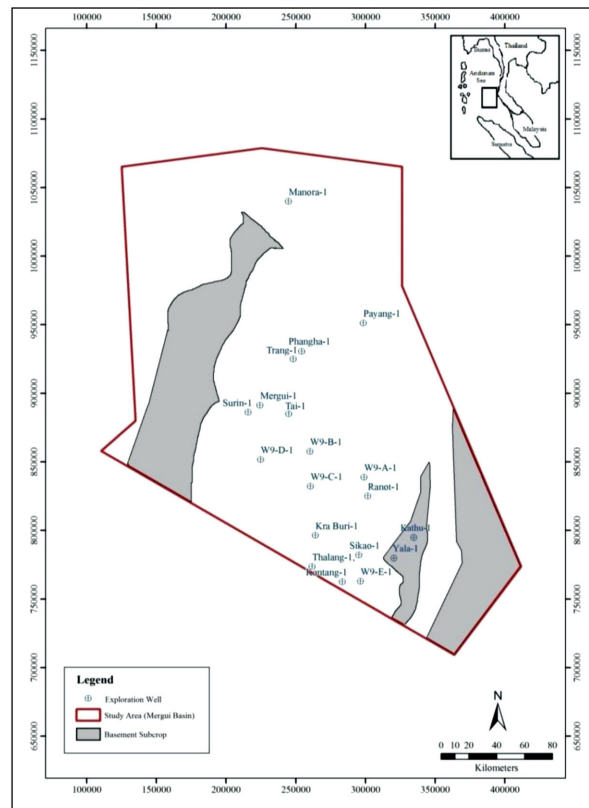
### Methods

Based on the available data, this research conducted some geochemical, mapping, and reservoir modeling techniques in order to study potential source rocks and a potential

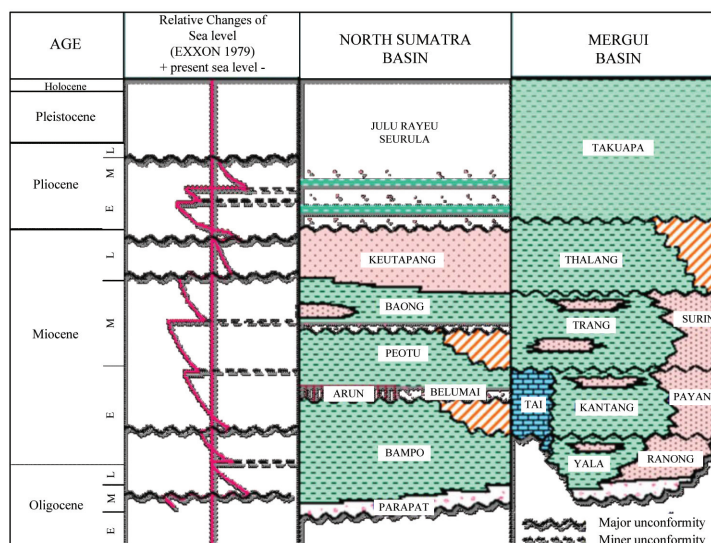
petroleum migration pathway of the Mergui basin. Results from the petroleum source rock analysis can be used to identify the type of organic matter, and the burial and local thermal history which is particularly important for the understanding of petroleum source rock maturity evolution. Petroleum have generally played a decisive role in the timing of migration versus trap formation and in the discrimination of oil and gas. Modern tools such as the PetroMod computer software of Schlumberger Oversea S.A. licensed to Suranaree University of Technology is available to unravel the various parameters involved. The selected reservoir potential was analyzed in order to draw a migration pathway of the petroleum and the important geological structures. The porosity versus depth sequence in the reservoir distribution was also assessed on sedimentary studies using all available geological and geophysical data. According to the porosity distribution maps, the thermal history, geothermal gradient, and petroleum migration pathway could be identified. Details of the research methodology are described as follows:

### Petroleum Source Rock Study

In order to study the maturity and organic richness of potential source rocks of the Mergui basin, some essential geochemical data, including kerogen types, hydrocarbon index (HI), oxygen index (OI), total organic carbon (TOC), Production Index (PI), and,  $T_{max}$ , etc., were collected and analyzed from the available sources. Three geochemical criteria required for a prospective source rock to be classified as an “effective” source for oil (effective being defined as capable of generating and expelling commercial quantities of oil) are organic enrichment, algal-amorphous (hydrogen-enriched) kerogen, and thermal maturity. Additionally, a good vertical and aerial extent of the source rock is also a geological requirement for its consideration as an effective source rock. Specific cutoffs for the geochemical criteria can be found in Espitalie *et al.* (1977); Hunt (1979); Bissada (1982); Tissot and Welte (1984).



**Figure 1.** Map of study area showing its entire area and its location, and the exploration wells the data of which were used in this study



**Figure 2.** Generalized stratigraphy of the Mergui basin and stratigraphic correlation to the North Sumatra basin (modified after Polachan, 1988)

### PetroMod Computer Software

PetroMod is a petroleum systems modeling software combined with seismic, well, and geological information to model the evolution of a sedimentary basin. The software predicts if, and how, a reservoir has been charged with hydrocarbons, including the source and timing of hydrocarbon generation, migration routes, quantities, and hydrocarbon type in the subsurface or at surface conditions (Schlumberger Oversea, 2010).

This research was used for modeling of the source rock maturity range and its efficiency in the selected W9-B-1 wells located in the eastern part of the Mergui basin. The selected W9-B-1 wells were shown, through the use of input data, to have details that were almost perfect for interpretation by the computer software. PetroMod software modeling is necessary in order to evaluate the source rock in terms of the continuing occurrence of subsidence, erosion, and the structure of the basin.

The input data available for this generation of computer software uses details such as

the formation, thickness, lithology, age of deposition, source rock property, boundary conditions, paleo-water depth (PWD), sediment water interface temperature (SWIT), and heat flow (HF). In order to evaluate the HF distribution in relation to the source rock, the burial history reconstruction and hydrocarbon generation timing, which are highly affected by the thermal condition of rifting, the temperature index ( $^{\circ}\text{C}$ ), and time temperature index (TTI), depict distribution with respect to the heat flow history, thermal conductivity of the rocks, and sediment water interface temperature variation, respectively, throughout time from the first time of expulsion, which depends primarily on the heat flow history and assigned kinetics (Habicht, 1979; Katz, 1991).

### Petroleum Migration Pathway Identification

In general, petroleum migration results from a buoyancy force, which is the main driving force. The buoyancy force is the principle of density difference by which low density material can move over high density material; so, oil and gas drive over the water

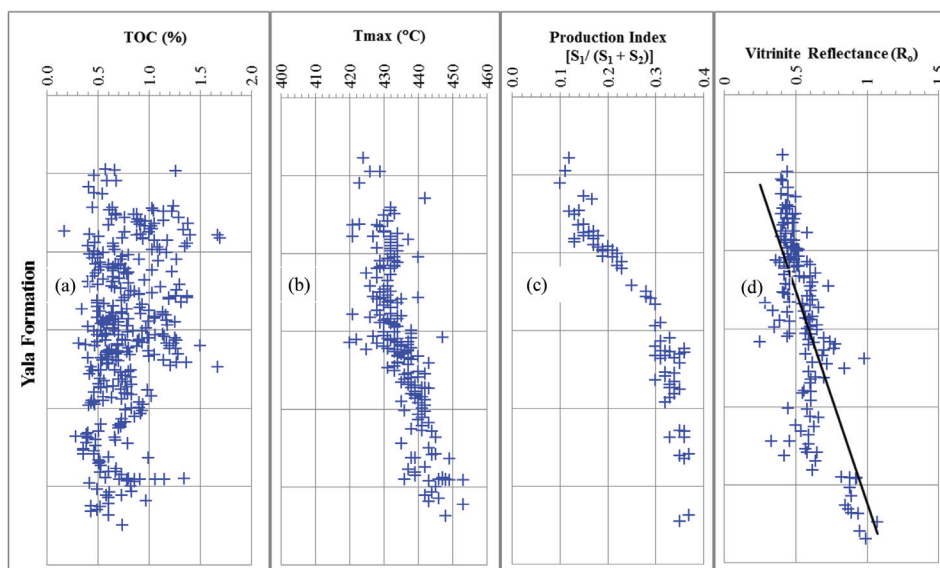


Figure 3. Results of pyrolysis (Rock-Eval) cutting samples of the Yala Formation; (a) TOC in wt%, (b)  $T_{\max}$  ( $^{\circ}\text{C}$ ), (c) Production Index (PI)  $[S_1 / (S_1 + S_2)]$ , and (d) Vitrinite reflectance ( $\%R_o$ )

formation. An obstacle to migration is a capillary force; if the rock has smaller pores, water, oil, or gas may hardly migrate, or may be trapped within this rock. Faults can act to support or obstruct the reservoir fluids' migration. The appropriate area for drilling should be considered from the local structure, stratigraphy, and distribution of the reservoir

rocks (Palciauskas, 1991).

In order to study the petroleum migration pathway of the Mergui basin, this research conducted some well studies only in the Ranong Formation which is a potential reservoir. The evaluation correlated the relationship of porosity versus depth.

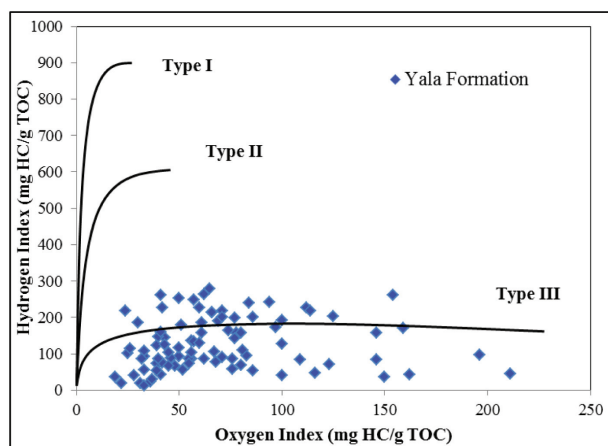


Figure 4. A plot of the Hydrogen Index (HI) versus the Oxygen Index (OI) of the Yala Formation indicating Type III kerogen

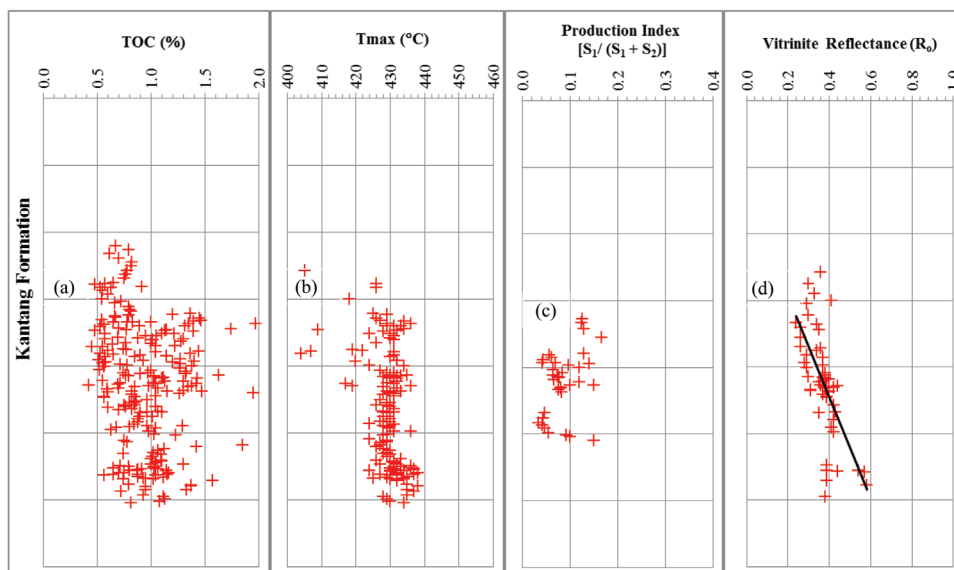


Figure 5. Results of pyrolysis (Rock-Eval) cutting samples of the Kantang Formation; (a) TOC in wt%, (b)  $T_{max}$  ( $^{\circ}\text{C}$ ), (c) Production Index (PI)  $[S_1 / (S_1 + S_2)]$ , and (d) Vitrinite reflectance ( $\%R_o$ )

## Result and Discussion

### Potential Petroleum Source Rock in the Mergui Basin

Based on previous studies of the source rock richness and kerogen type of the Mergui basin that were evaluated using standard Rock-Eval pyrolysis and visual kerogen analyses, all the petroleum geochemical studies were considered and re-interpreted.

Unfortunately, the Rock-Eval pyrolysis analyzed only the sidewall cores and cuttings from the Yala, Kantang, and Trang Formations.

The results of the sources of 18 wells that were presented in the TOC analysis of the Yala Formation indicated that the marine shale of the late Oligocene to early Miocene periods has TOC values ranging between 0.5 and 1.5% (Figure 3(a)) and generally comprise a type III terrestrial, which is a gas

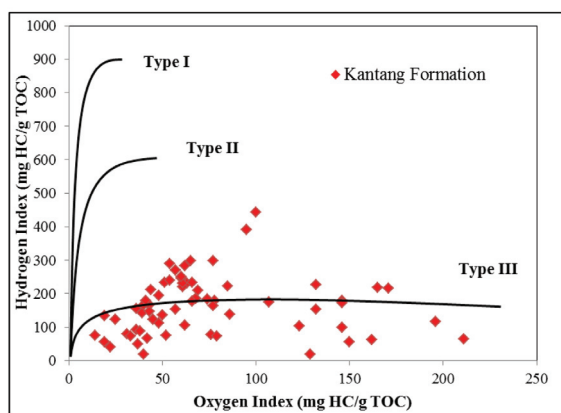


Figure 6. A plot of the Hydrogen Index (HI) versus the Oxygen Index (OI) of the Kantang Formation indicating a mix of Type II and Type III kerogen

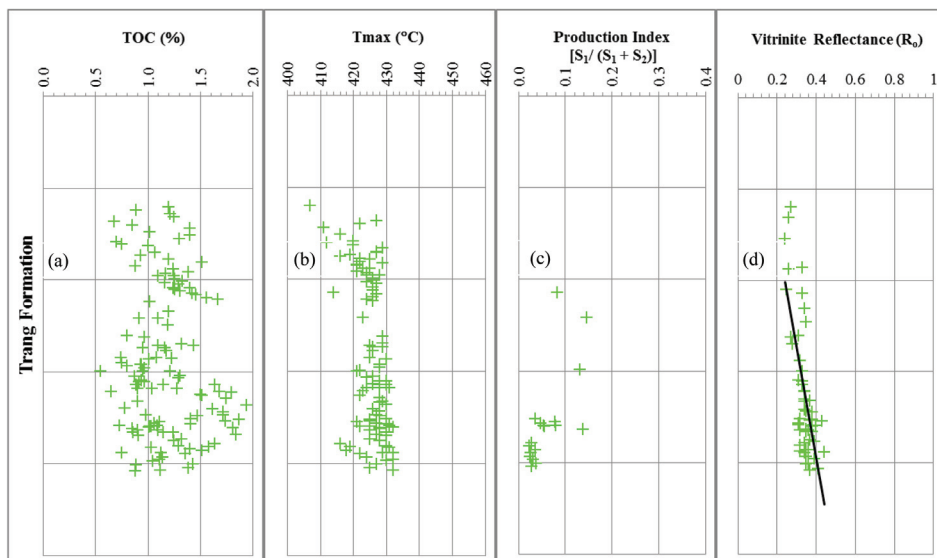


Figure 7. Results of pyrolysis (Rock-Eval) cutting samples of the Trang Formation; (a) TOC in wt%, (b)  $T_{max}$  (°C), (c) Production Index (PI)  $[S_1 / (S_1 + S_2)]$ , and (d) Vitrinite reflectance ( $\%R_o$ )

prone kerogen (Figure 4). This is like the early Miocene Kantang Formation that has a fair to good TOC value range between 0.5 and 1.5% (Figure 5(a)) and consists of a mixture of type II and type III kerogen (Figure 6), whereas the middle Miocene Trang Formation has a fair to very good TOC range between 0.5 and 2.0% (Figure 7(a)), which consists of type II and type III kerogen as it is an older formation (Figure 8).

### Thermal Maturity and Timing of Hydrocarbon Generation and Migration

Thermal maturity of source rocks can be evaluated by using the Rock-Eval pyrolysis, hydrocarbon geochemistry, and vitrinite reflectance ( $R_o$ ). Plots of the  $T_{max}$  (degree Celsius), production index, and  $R_o$

(percentage) versus the depth of the Yala, Kantang, and Trang Formations are shown in Figures 3, 5, and 7, respectively.

Results from the  $T_{max}$  and  $R_o$  plots indicated that the Yala Formation (Figure 3) has a  $T_{max}$  range between 430°C to nearly 450°C (Figure 3(b)), and an  $R_o$  range between 0.6 and 1.0% (Figure 3(d)). The Kantang Formation has a  $T_{max}$  very close to the Yala Formation being in a range between 420°C and 440°C (Figure 5(b)), whereas it has a lower  $R_o$  than the Yala Formation with a range between 0.2 and 0.6% (Figure 5(d)). The Trang Formation has a  $T_{max}$  and  $R_o$  less than both the Yala and the Kantang Formations as its  $T_{max}$  is in a range between 400°C and 430°C (Figure 7(b)) and its  $R_o$  is in a range between 0.2 and 0.4% (Figure 7(d)).

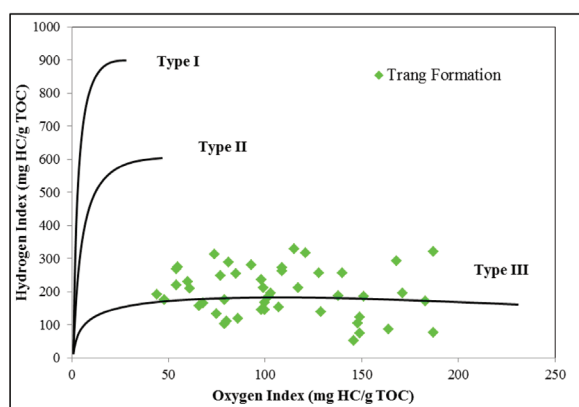


Figure 8. A plot of the Hydrogen Index (HI) versus the Oxygen Index (OI) of the Trang Formation indicating a mix of Type II and Type III kerogen

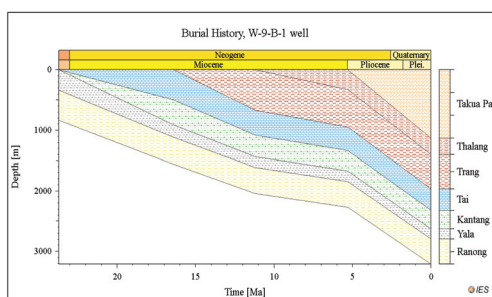


Figure 9. Burial history of the W9-B-1 well calculated using PetroMod Software

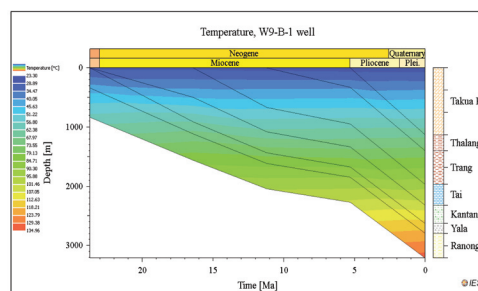


Figure 10. Temperature Index (°C) calculated using PetroMod Software of the W9-B-1 well



The PI is the ratio of already generated hydrocarbon to potential hydrocarbon  $[S1/(S1 + S2)]$  derived from the Rock-Eval pyrolysis. The PI value in a range between 0.15 and 0.40 indicates hydrocarbon generation. A low PI value (less than 0.01) indicates immaturity or extreme post-maturity organic matter. High PI values indicate either the mature stage or contamination by migrated hydrocarbons or drilling additives (Peters and Cassa, 1994). Results from the PI versus depth plotting of the Yala Formation (Figure 3(a)) indicated that its PI increased regularly with the depth from 0.10 to nearly 0.4, whereas the Kantang Formation has a lower PI value which is in the range between 0.02 and 0.15 (Figure 5(a)), and the Trang Formation has a very narrow PI value in the range between 0.1 and 0.14 (Figure 7(a)), respectively.

### PetroMod Computer Software Result

The PetroMod modeling of the burial and thermal history reconstruction was derived from the PWD, SWIT (using the Southeast Asia zone), and HF that were inputted regularly with the age of subsidence in the case of the Mergui basin study. The burial history reconstruction subsidence was shown generated on the W9-B-1 wells (Figure 9).

The temperature Index (°C) and TTI depicted the thermal conductivity of the rocks from the time of the first expulsion. The TTI value, which is in the range between 15 and 160 is hydrocarbon generation, and the TTI value 65 is the maximum expulsion of hydrocarbon from the source bed (Waples, 1980). Results from the Temperature Index versus depth plotting in the W9-B-1 wells indicated that the Temperature Index increased regularly with the depth from 23.30°C to nearly 134.96°C (Figure 10). Likewise, the TTI versus depth plotting of the W9-B-1 wells indicated that the TTI increased regularly with the depth from 0.02 to nearly 25.47 (Figure 11). Thus, PetroMod evaluated that the W9-B-1 wells started early hydrocarbon generation at a depth greater than 1900 m. The hydrocarbon generation efficiency calculations and the measurement of  $R_o$  values are as determined by EASY% $R_o$  (Sweeney and Burnham, 1990). Results from the  $R_o$  versus depth plotting of the W9-B-1 wells indicated a mature (cut off:  $R_o$  between 0.6 and 0.8) depth approximately greater than 2500 m (Figure 12).

After comparing the results from the analyzed available data sources by geochemistry technique and PetroMod computer software of the W9-B-1 wells, the available data source by the geochemistry

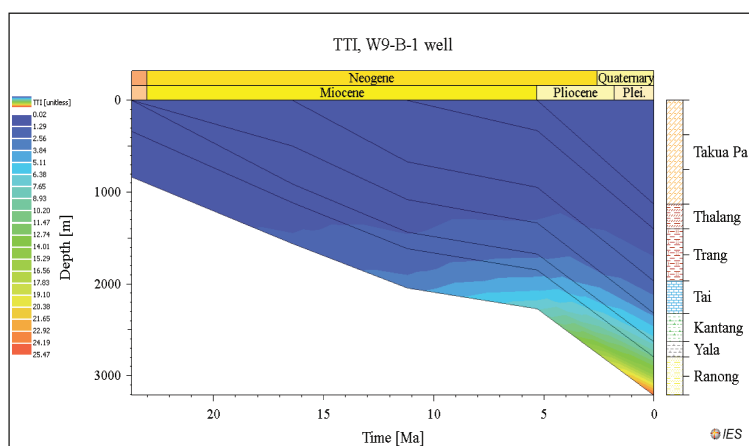


Figure 11. Time Temperature Index (TTI) calculated using PetroMod Software of the W9-B-1 well



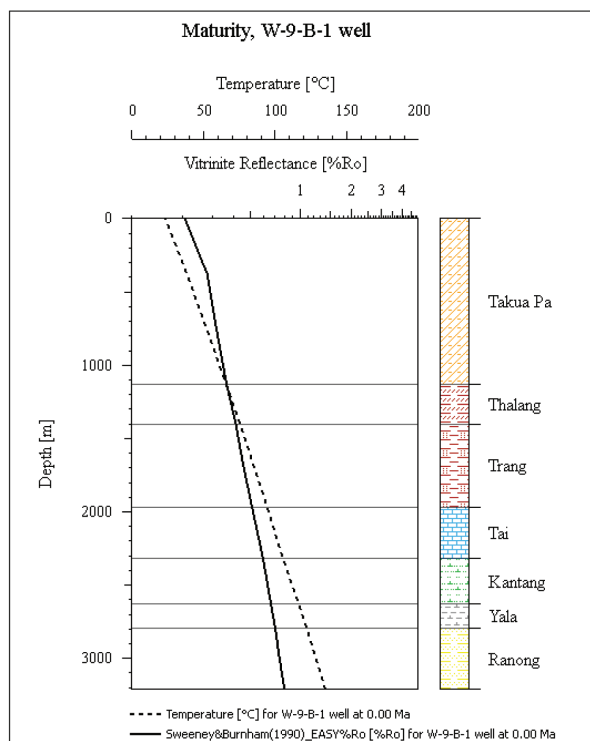
technique was chosen to build the basin modeling in this study. This was because the model resulting from the geochemistry technique worksheet has more suitable values than that of PetroMod, hence it can generate the best output. The thermal history and hydrocarbon generation information from PetroMod was less than that from the geochemistry technique worksheet.

According to the re-interpretation of the geochemistry data, the PetroMod computer software can predict immaturity throughout the basin. In the study of the source rock of the 18 wells the results showed almost all the source rock was immature, while the mature source rock which predicted the generation of an oil window was indicated by the geochemistry technique and PetroMod. Vitrinite reflectance indicates that the oil window lies around 2100 m, 3000 m, and

4500 m in the north Mergui basin, main Mergui basin, and Andaman slope areas, respectively. The Oligocene to early Miocene period Yala Formation is mature over most of the basin, while the early Miocene Kantang Formation is mature in the depocenters of the isolated sub-basins. The middle Miocene period Trang Formation and younger formations are immature over most of the basin. The principal control on the distribution of mature source rocks appears to be a combination of the structural history and geothermal gradient.

### Petroleum Migration Pathway

Based on the available porosity data which were collected from the selected wells, the relationship of porosity versus depth of the Ranong Formation had plotted trends, as shown in Figure 13.



**Figure 12. Maturity overlay Ro compare with temperature and depth calculated using PetroMod Software of the W9-B-1 well**

According to re-interpretation of the sedimentology and petrography of the Mergui basin, it is predicted that sandstone potential reservoirs occurred throughout most of the succession, especially in the Ranong, Payang, and Surin Formations. Thick deltaic and shallow marine sandstones of the Ranong Formation probably rate as the most promising reservoir intervals, while middle fan turbidite sands of the Yala Formation and shallow marine sandstones of the Payang Formation may also form potential reservoirs. The limestones of the Tai Formation may also constitute a potential reservoir where they have been fractured and/or karstified. Although petrographically these limestones are tight, most of the wells which have penetrated the Tai Formation to date have lost circulation due to the presence of large cavities which may have formed through karstification during exposure in the middle Miocene period.

Thermal maturity of the sedimentary section to initiate primary migration within

the Mergui basin appears to have begun around the middle Miocene period and continues until today. The occurrence of hydrocarbons within the Mergui basin can be explained in terms of mature source rock locations and migration pathways (Figure 14). Hydrocarbons primarily move laterally from mature source areas updip along unconformities and/or via permeable carrier beds while faults tend to block and redirect hydrocarbon migration. Figure 14 depicts that the hydrocarbons in the Mergui basin are primarily being generated and migrating from the deep east Mergui, west Mergui, and Ranong troughs. However, this suggestion must be confirmed by the location of kitchen areas which have high potential to produce petroleum and must accompany good migration pathways and trap mechanisms within the source beds. Unfortunately, the low expulsion efficiency of the source strata is problematic across the Mergui basin and is the result of a high percentage of coarser clastic (silt to very fine grain sandstone) contamination.

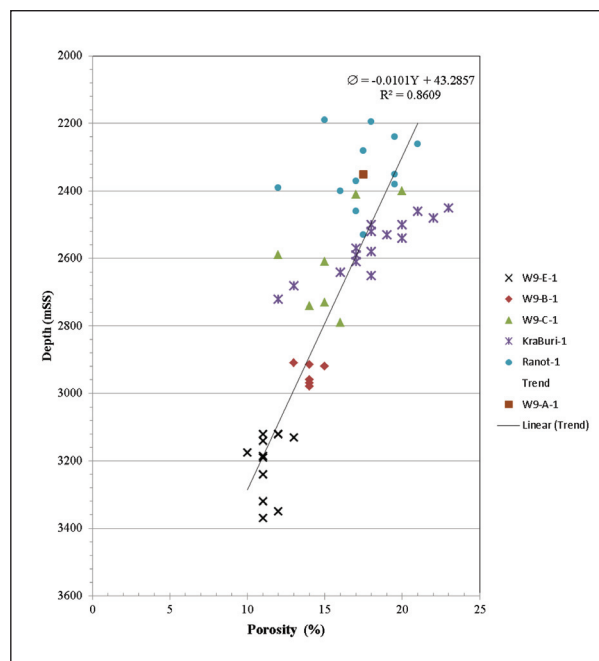


Figure 13. Relationship between porosity versus depth of the Ranong Formation

## Conclusions and Recommendations

After the study had been completed, some conclusions were listed as follows:

Results from the source rock maturity study in the Yala, Kantang, and Trang Formations indicated that only the Yala Formation has potential source rocks (gas prone kerogen) and they are mature over most of the basin, whereas the source rocks

of the Kantang and the Trang Formations (oil/gas prone kerogen) are considered immature. Vitrinite reflectance indicates that the oil window lies around 2100 m, 3000 m, and 4500 m in the north Mergui basin, main Mergui basin, and Andaman slope areas, respectively.

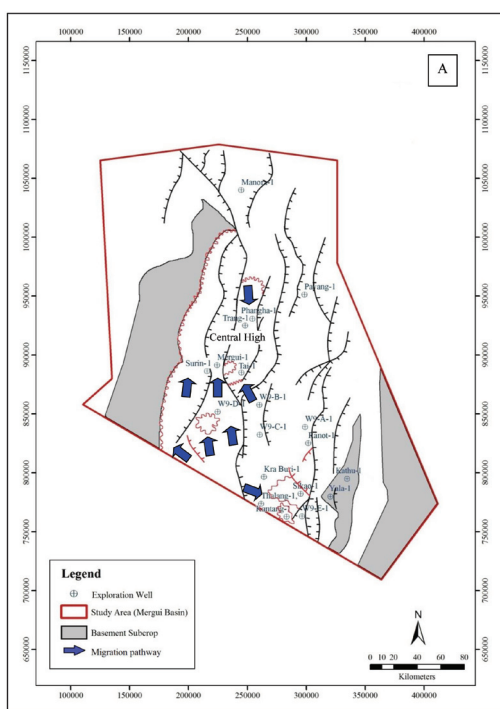
Results from the sandstone porosity data study which indicate potential reservoirs in the Ranong Formation considered together with the thermal maturity of the sediment show which section initiated primary migration. The Mergui basin appears to have had its initial primary migration beginning around the middle Miocene period and continues until today. Hydrocarbons are primarily being generated and are migrating from the deep east Mergui, west Mergui, and Ranong troughs.

## Acknowledgement

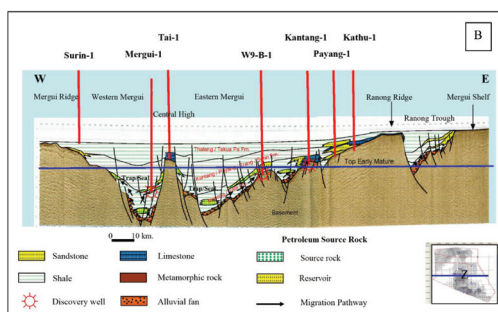
The research work presented in this paper was supported and funded by Suranaree University of Technology. The permission of the Department of Mineral Fuels, Ministry of Energy, to use the necessary data for undiscovered hydrocarbon assessment is also greatly appreciated. The authors would like to thank Assoc. Prof. Kiangkrai Trisarn and Dr.Chongphan Chonglakmani for their valuable suggestions.

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(a)



(b)

**Figure 14.** Possible migration pathways in the Mergui basin (A, B)

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