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2D Petroleum System Modelling and Hydrocarbon Potentiality of Huai Hin Lat Formation, Khorat Plateau, Thailand

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Abstract

Huai Hin Lat Formation has been known as significant source rock for petroleum system in Khorat Plateau, North East Thailand. It is believed to commence depositing in an initial rift sequences since and through Triassic period associated with Indosinian orogeny which catastrophically influences over source rock characterization in Thailand. The integration of geological acquisition, geochemical analysis and geophysical approaches has been applied to evaluate hydrocarbon potentiality of Huai Hin Lat Formation in the aspects of generation, qualification and migration. The studied outcrop is composed of organic shale, sandstone and interbedded layers Total Organic Carbon (TOC) range from 0.02 to ~1 wt.% which is poor to fair for petroleum potential. Kerogen is classified as type III (gas-prone) considered by low Hydrogen Indices (HI) and high Oxygen Indices (OI). While thermal indicator, Maximum Temperature (T_{max}) range in 348°C to 545°C mentioned immature and postmature stage agreed with Vitrinite Reflectance (R_o%), ranging in high values of 1.60 to 1.91. Extractable Organic Matter (EOM), fall in the very low range of 19.81-79.94 ppm, which are immature. Most of Pristane to Phytane (Pr/Ph) ratios are more than 3.0 suggested terrigenous organic matter deposited under oxic to suboxic condition inferring to lacustrine environment, Pristane to Heptadecane (Pr/n-C17) and Phytane to Octadecane (Ph/n-C18) figure out paleo-depositional environment of organic matter as high oxidizing terrestrial area which can provide kerogen type III. Seismic interpretation reflected rifting system geometry in which Huai Hin Lat Formation was found in half-graben and also conformably lay over Permian carbonate which is expected reservoir. However, there is no evident of migration pathway can be observed in 2D petroleum system models. Moreover, maturity model showed late stage of maturity according to the high present-day temperature model (over 100°C) and supportively with high hydrocarbon transformation ratio model. Considering via less promising in hydrocarbon generation, rather poor in hydrocarbon qualification, high degree of maturation and restricted hydrocarbon migration, Huai Hin Lat Formation in this study is concluded to possess low hydrocarbon potentiality.

Keywords: 2D Petroleum modelling, Hydrocarbon Potentiality, source rock evaluation, Huai Hin Lat Formation, Khorat Plateau

1. Introduction

Huai Hin Lat Formation is believed to be a potential source rock in Khorat Plateau petroleum system, deposited among the period of high intensity of tectonic activities which can encourage to prepare an expectedly good source rock for the productive gas fields in northeastern Thailand (Booth and Sattayarak, 2011). The different locations of geological study may have either common or different characteristic of source rock. Phetchabun Province is a suitable spot settled in the dramatically active tectonic district at the west margin of Khorat Plateau which possibly reflect an interesting characterization of source rock based on the same hypothesis but different in available data. Some doubts pertaining to hydrocarbon charging potentiality of Huai Hin Lat Formation; for instance, the existence of source rock, the possibility of hydrocarbon generation, the opportunity of hydrocarbon expulsion and migration from Huai Hin Lat source rock to accumulate in a reservoir via migration pathway created by local tectonic mechanism. Hence, to assess those promising potentialities, this study has been set up by applying geological observation for detecting interesting sedimentological and structural features, geochemistry for determining the natural substances recorded in engaged source rock, geophysics for defining distinguished seismic features which can tell the ancient story of the Khorat Plateau, and eventually geomodelling for displaying the whole integrated dataset into the conclusion. To create 2D petroleum system modelling and reconstruct basin evolution by PetroMod software are the effective method to receive a better understanding on the nature of hydrocarbon potential and characteristics from Huai Hin Lat Formation in Khorat Plateau.

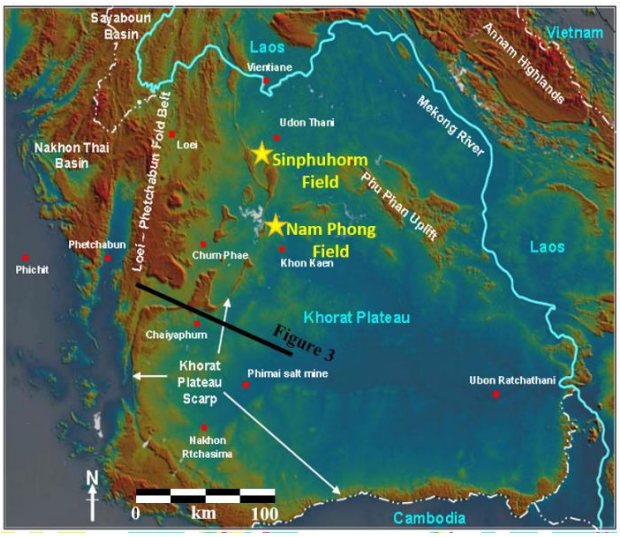


Figure 1. The setting of Khorat Plateau basin which can be divided to two major sub-basins namely Khorat Basin in the south and Sakon Nakorn Basin in the north by Phu Phan Range orogeny. (Modified after Racey A. and Goodall J., 2009).

2. Region geological setting

Khorat Plateau has previously been investigated through time by many researchers e.g., Ward and Bunnag, 1964; Sattayarak, 1983; Mouret et al. , 1993; Meesook, 2001; Racey, 2009., covers the whole part of northeastern Thailand, possesses an area over 200,000 km^2 (Chantong, 2007)., with the remainder covering parts of southwestern Laos and northern Cambodia as shown in **Figure 1.** Khorat Plateau is divided by the Phu Phan Range into two sedimentary sub-basins, the Khorat Basin in the south and the smaller Sakhon Nakhon Basin in the north. The dominant landforms are low hills and ridges with board crests and gentle straight slopes of 20 to 30 m relief separated by broad valleys (Löffler et al, 1984). The sedimentary sequence consists mainly of the Mesozoic non- marine red beds known as Khorat Group, which is unconformably overlain by continental evaporites of the Maha Sarakham Formation and eaolian sandstone of the Late Cretaceous to Early Tertiary? Phu Tok Formation. The Khorat group is underlain by the older rocks including the Late Triassic fluvial and lacustrine sediments of the Huai Hin Lat Formation, the Palaeozoic marine sediments of the Permian Saraburi Group; Nam Duk Formation and the Pha Nok Kao Formation, platform Permian limestone, and Hau Na Kam Formation; the Devonian to the Lower Carboniferous Pak Chom Formation and the Silurian- Devonian? Na Mo Formation.

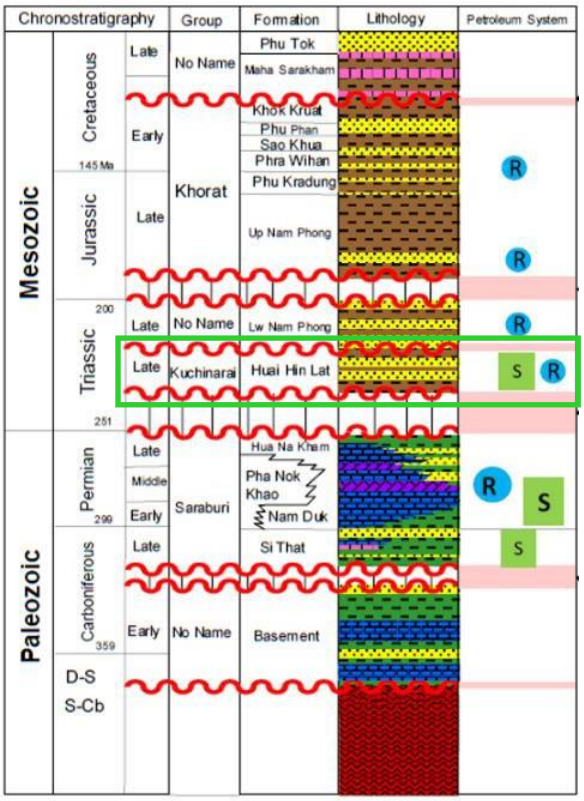


Figure 2. Tectono-stratigraphic column from Paleozoic and Mesozoic succession of Khorat Plateau (Minezaki, 2019).

Triassic Huai Hin Lat Formation

As a result of Indosinian I orogeny occurred on top of Permian carbonate (Saraburi Group) sequences, inverted fault structures can be observed throughout Lat Carboniferous to Permian time. Triassic rifts are also inverted in some parts of the Khorat Plateau shown in **Figure 3**. An obvious angular unconformity is overlain by Huai Hin Lat Formation and underlies the Khorat Group with a local unconformity. This sequence is represented as the Huai Hin Lat Formation that comprises with shale, sandstone, limestone, conglomerate and possibly volcanic rocks. The Huai Hin Lat Formation can be divided into two facies including the dark gray sediments and the brownish red sediments by lake sedimentary rocks.The western rim of the plateau is

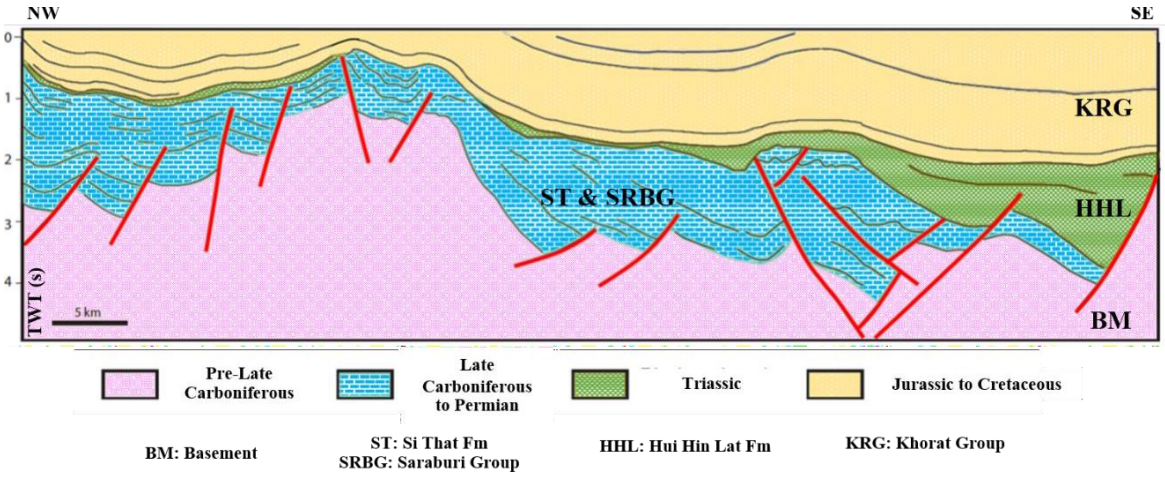


Figure 3. Cross-section through the western rim of Khorat Plateau, Location can be seen in **Figure 1**

essentialized by this study as the representative field study area where is still lack of academic prove and also is able to support the existence of chronological tectonic event associated with the creation of Khorat Plateau Basin.

3. Methodology

To evaluate hydrocarbon potentiality of Huai Hin Lat Formation in the aspects of hydrocarbon quantity, quality, maturity and possibility of migration, this study has been performed geological acquisition, geochemical analysis and geophysical approaches and finally presented in 2D petroleum system model through the application of PetroMod software.

Petroleum system modelling is performed by firstly preparing depth-based 2D seismic profile by converting in Petrel 2017 software to generate the model geometry since a seismic profile is generally in two-way-travel time (TWT). The conversion can be done by using the relationship between P-wave velocity of any types of rock called velocity model. Velocity is a geophysical property which is depended on the characteristic nature of rock, for instance; grain size, grain shape, porosity, density, compaction etc. It is important to convert time to depth domain of the seismic section because it eliminates the structural uncertainty involved with time and confirms the structure at certain depth. Seismic features both stratigraphic horizons (tens layers differentiated by nine reflectors) and faults definition (nineteen faults) as interpreted in Petrel software will subsequently be digitized in PetroMod software to draw a model geometry. In the first place, ten stratigraphic layers were distinguished by the criteria of different seismic reflector as Formation tops; including Basement rock, Si That Formation, 3 facies of Permian carbonate (Saraburi Group), Huai Hin Lat Formation, Khorat Group and Maha Sarakham with Phu Tok Formation. Then interval velocity is assigned as shown in **Table 1.**

Table 1. Interval velocity of each Formation entered into Petrel 2017 program based on various literatures.

Base			Correction	Model		
Surface	9PTnMH5	None	V=V0+VInt	V0: Constant	4000
Surface	8KR	None	V=V0+VInt	V0: Constant	4550
Surface	7NP	None	V=V0+VInt	V0: Constant	3030
Surface	6IDSN2	None	V=V0+VInt	V0: Constant	4710
Surface	5IDSN1	None	V=V0+VInt	V0: Constant	4800
Surface	4SRBP2	None	V=V0+VInt	V0: Constant	4250
Surface	3SRBP1	None	V=V0+VInt	V0: Constant	4300
Surface	2ST	None	V=V0+VInt	V0: Constant	4800
Surface	1BM	None	V=V0+VInt	V0: Constant	5000

3.1 Modelling procedures

The model building procedures include 1) Model geometry digitization, 2) Fault properties assignment, 3) Age and layers assignment, 4) Layer splitting 5) Facies definition, 6) Boundary conditions assignment and 7) Perform running the simulator.

3.1.1 Model geometry digitization

The horizons and faults of seismic sections were interpreted based on the quality and configuration of the reflectors and depth converted for modelling of the petroleum systems. The PetroMod software was used for modelling the sections. It is crucial to convert the section from time to depth domain because PetroMod software accepts the section which is in depth-

domain for modelling. Generally, the reflectors on the seismic section differ in character, amplitude and continuity

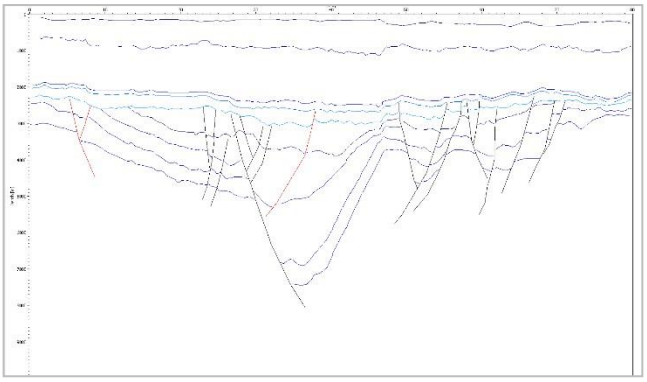


Figure 4. Pre-grid model view after digitizing horizons and faults

3.1.2 Faults properties assignment

The properties of faults can be defined including period, age and type of the faults. The age of the faults was assigned many of ages. Plus, faults can be defined as open (non-sealing) and close (sealing)at different time intervals. During rifting the faults were possible open or close.

Table 2. Faults properties definition for Khorat Plateau modelling.

Name	-	Period	Age from [Ma]	Age to [Ma]	Type	Name	-	Period	Age from [Ma]	Age to [Ma]	Type
North_4		1	260.00	241.00	Open	North_4		1	260.00	241.00	Closed
South_5		1	280.00	241.00	Open	South_5		1	280.00	241.00	Closed
South_4		1	260.00	241.00	Open	South_4		1	260.00	241.00	Closed
North_3		1	330.00	241.00	Open	North_3		1	330.00	241.00	Closed
South_3		1	260.00	209.00	Open	South_3		1	260.00	209.00	Closed
South_2		1	330.00	241.00	Open	South_2		1	330.00	241.00	Closed
North_2		1	299.00	241.00	Open	North_2		1	299.00	241.00	Closed
North_5		1	323.00	209.00	Open	North_5		1	323.00	209.00	Closed
South_13		1	323.00	209.00	Open	South_13		1	323.00	209.00	Closed
South_12		1	340.00	241.00	Open	South_12		1	340.00	241.00	Closed
South_11		1	330.00	209.00	Open	South_11		1	330.00	209.00	Closed
South_10		1	340.00	241.00	Open	South_10		1	340.00	241.00	Closed
South_9		1	299.00	201.00	Open	South_9		1	299.00	201.00	Closed
North_6		1	330.00	209.00	Open	North_6		1	330.00	209.00	Closed
South_8		1	323.00	209.00	Open	South_8		1	323.00	209.00	Closed
South_7		1	323.00	209.00	Open	South_7		1	323.00	209.00	Closed
North_1		1	323.00	241.00	Open	North_1		1	323.00	241.00	Closed
South_1		1	330.00	241.00	Open	South_1		1	330.00	241.00	Closed
South_6		1	280.00	209.00	Open	South_6		1	280.00	209.00	Closed

3.1.3 Age and layers assignment

The age information **(Table 3.)** was taken from various published literatures. Three major erosions were assigned to the age assignment table, Tertiary erosion which eroded 2000m of layer thickness, Mid-Cretaceous erosion which eroded 1000m of Khorat Group layer thickness (O' Leary and Hill, 1989), Indosinian II unconformity and Indosinian I unconformity. The oldest reflector is Late Carboniferous Si That Formation, which is around 323 Ma and youngest reflector is the Top Quaternary sediments.

Table 3. Age assignment table defining the commence of each reflector

3.1.4 Layer splitting

The previously assigned layers can be split to enhance the obviousness of basin. In this case, Khorat Group was split into 7 layers representing the members of Khorat group as the proportion of thickness.

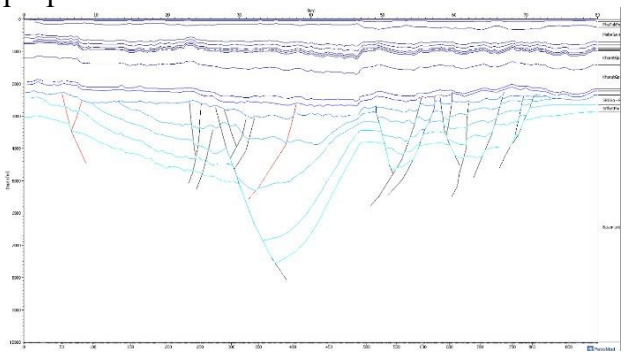
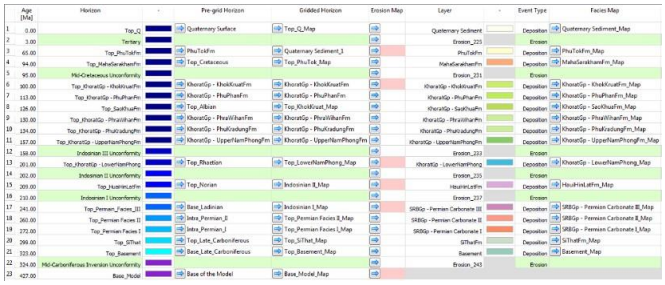


Figure 5. After layer splitting, 16 layers can be seen in 2D view window in PetroMod software.

Table 4. After layer splitting, age and layers assignment need to be adjusted

After splitting the possible layers, the details regarding scenarios in the Khorat Plateau basin can be added including type of events (deposition; erosion or hiatus) or unconformity events to determine the major tectonic history which can be affected to source rock efficiency.

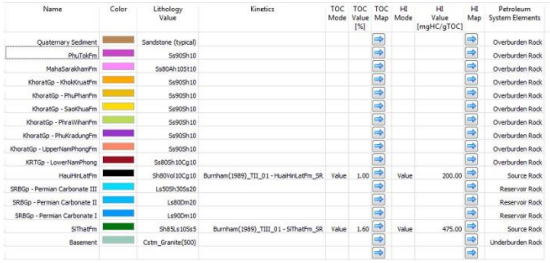
Table 5. Add the details regarding type of events including deposition, erosion or hiatus to determine the major tectonic history which can affected to source rock efficiency.



3.1.5 Facies definition

To define facies of different layers can facilitate to petroleum system stimulation of Khorat Plateau. Basement rocks are assumed to be granitic igneous which is base of model. Si That and Huai Hin Lat Formation are assigned as the source rocks. 1 wt.% TOC and 200 ppm HI of Huai Hin Lat Formation obtained from geochemical analysis were input to the model for displaying petroleum potentiality. TOC and HI put in Si That Formation came from source ideology. The rest of layers were assigned as overburden rock.

Table 6. Facies definitions totally 16 layers were put in the model



3.1.6 Boundary conditions assignment

Boundary conditions define the basic energetic conditions for temperature and burial history of the source rock and, consequently, for the maturation of organic matter through time(PetroBuilder 2D_User Guide version 2017). Three main boundary conditions were defined during modelling of the basin these are; paleo water depth (PWD), heat flow (HF) and sediment-water interface temperature (SWIT). Emphasized on Khorat Plateau studies, heat flow is approximately 60 - 80 mW/m^2 (Doust & Scott Summer, 2007) while Thienprasert and Raksasakulwong (1982) mentioned that heat flow can be very high (above 100 mW/m^2). High value of heat flow can affect to the hydrocarbon maturity level of source rock in this region.

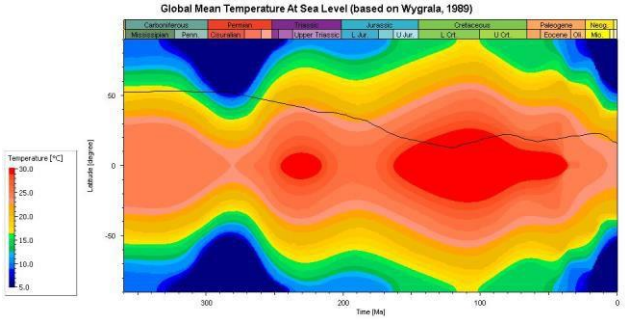


Figure 6. Sediment Water Interface Temperature (SWIT) definition

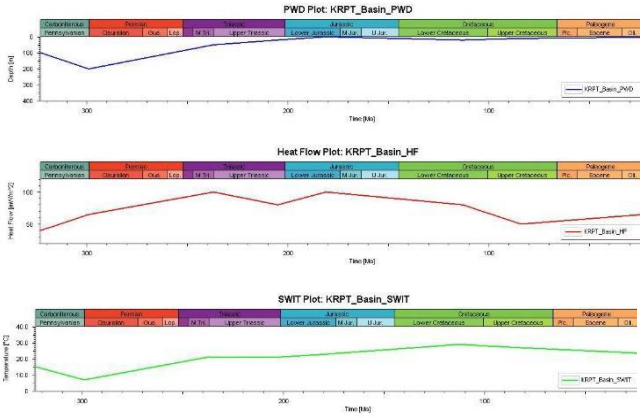


Figure 7. Boundary conditions trends for Khorat Plateau Basin model. (a) anticipated Paleo-water depth, (b) anticipated heat flow, (c) Auto SWIT (Sediment-water Interface Temperature)

4. Results and discussion

4. 1 Interpreted basin evolution

Burial history, erosion and uplift events can be displayed throughout geological time. The Khorat Plateau has been affected by major events in regional tectonic history. After rifting from Gondwana in which basement rocks and Si That Formation deposited in Late Carboniferous, then the Permo-Triassic collision between Sibumasu and Indochina block causing the closure of paleo-Tethys, and allow basinal sediment deposit on top of Permian carbonate platform which is inferred as conglomeratic limestone of Huai Na Kam Formation which according to the change of seismic facies. Erosion and uplift at Khorat Plateau occurred along Mezosoic and Cenozoic

which have significantly affected the petroleum system.

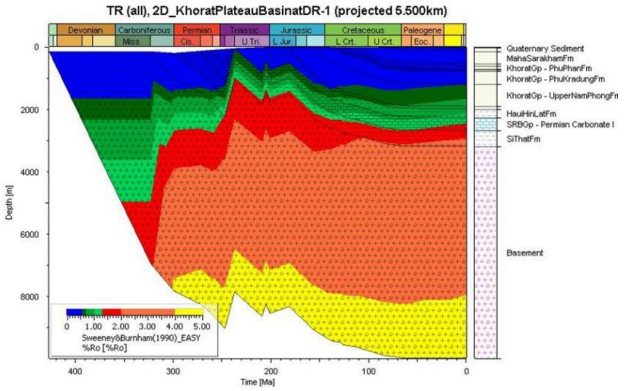


Figure 8. The 2D burial history model of Khorat Plateau representing by thermal maturity

Generally, when the area is uplifted and then eroded it tends to be exposed, temperatures subsequently drop down which can dramatically affect to source rock maturity. The petroleum system of Khorat Plateau, considered from the interpreted seismic profile, consists of two source rocks including Late Carboniferous Si That Formation and Late Triassic Huai Hin Lat Formation (which is spotted in this study). Reservoir rocks is Permian carbonate of Saraburi Group (which can be divided into three facies). However, the most common reservoir is known as the lowest facies Pha Nok Kao Formation. Seal rocks can include the Late Triassic Huai Hin Lat Formation (Carnian to norian) and Lower Nam Phong Formation (Rhaetian), both of which comprised with conglomerate, claystone and shale. Both structural and stratigraphic traps are found in this rifting system basin. The maturation of the hydrocarbons from the Late Triassic can let hydrocarbon generated as gas prone. The area of Khorat Plateau Basin has been affected by many tectonic events since the Caledonian Orogeny in Early Devonian times, then Variscan Orogeny in Late Silurian to Early Carboniferous, after that Mid Carboniferous unconformity was followed by the Late Carboniferous rifting. During Late Permian to nearly Late Jurassic, Indosinian orogeny has played a crucial role in tectonic control. Mid Cretaceous inversion caused the sediments Khorat Group disappeared around 1000 meters. Next, Himalayan Orogeny has participated at the beginning of Tertiary till Mid-Miocene inversion which caused erosion of Tertiary sediments in Khorat Plateau up to 3000 meters. Modern sedimentation, nowadays, is unconsolidated sediments of Quaternary age.

4.2 Source rock maturity

The engaged Triassic source rocks, Huai Hin Lat Formation, are displayed by geochemical inputs put in the model. Si That source rock is over matured and reaches the dry gas window at the deepest parts of the basin at the present day. Whereas the Huai Hin Lat Formation is still displayed in immature to postmature stage which can be generating both oil and gas. The potential of oil generation is not realistic and not according to the geochemical analysis data. The hydrocarbon maturation displaying in present-day temperature, vitrinite reflectance (Sweeny & Burnham 1990) and transformation ratio models increase with burial history shown in depth.

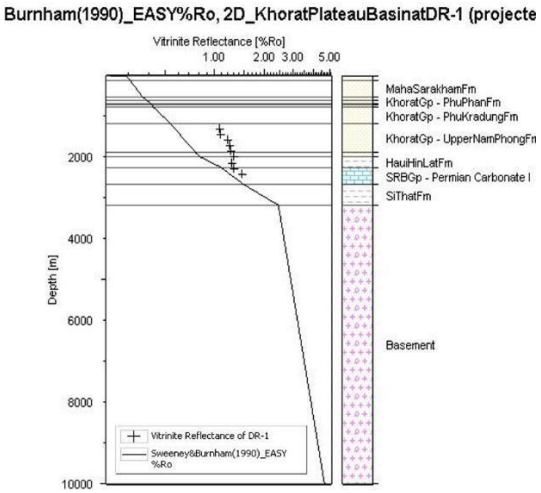


Figure 9. 2D petroleum system model calibration using vitrinite reflectance from well DR-1 as the nearest well reference.

Thermal maturation indicators for calibrating models are vitrinite reflectance from public domain well DR-1 (prototype drilling well in the northeastern region) which is nearest to the interpreted seismic line and can be used as depth reference.

Referring to Figure 13, the hydrocarbon saturation model shows the interesting closure area (the middle left) with high saturation of hydrocarbon where is probably a good place for hydrocarbon accumulation. In this case, Huai Hin Lat Formation acts as a seal instead of source which can preserve hydrocarbon in Khorat Plateau petroleum system.

4.3 Hydrocarbon migration

As shown in **Figure 13.** the habit of the hydrocarbon migration is vertically upward or downward from the Huai Hin Lat (black layer) and Si That Formation (lowermost dark green layer) source rocks towards Permian reservoir rock (from dark blue to light blow, ascendingly). The expected migration pathway is along major faults and within the carrier beds like reservoir layer itself as well. Migration at some area of the model can be occurred by leaking at the failure point (the middle right at the contact of black and light blue layer) resulting hydrocarbon accumulation in the layer of Khorat Group member which is overlain by evaporitic lithofacies Maha Sarakham formation (pink layer).

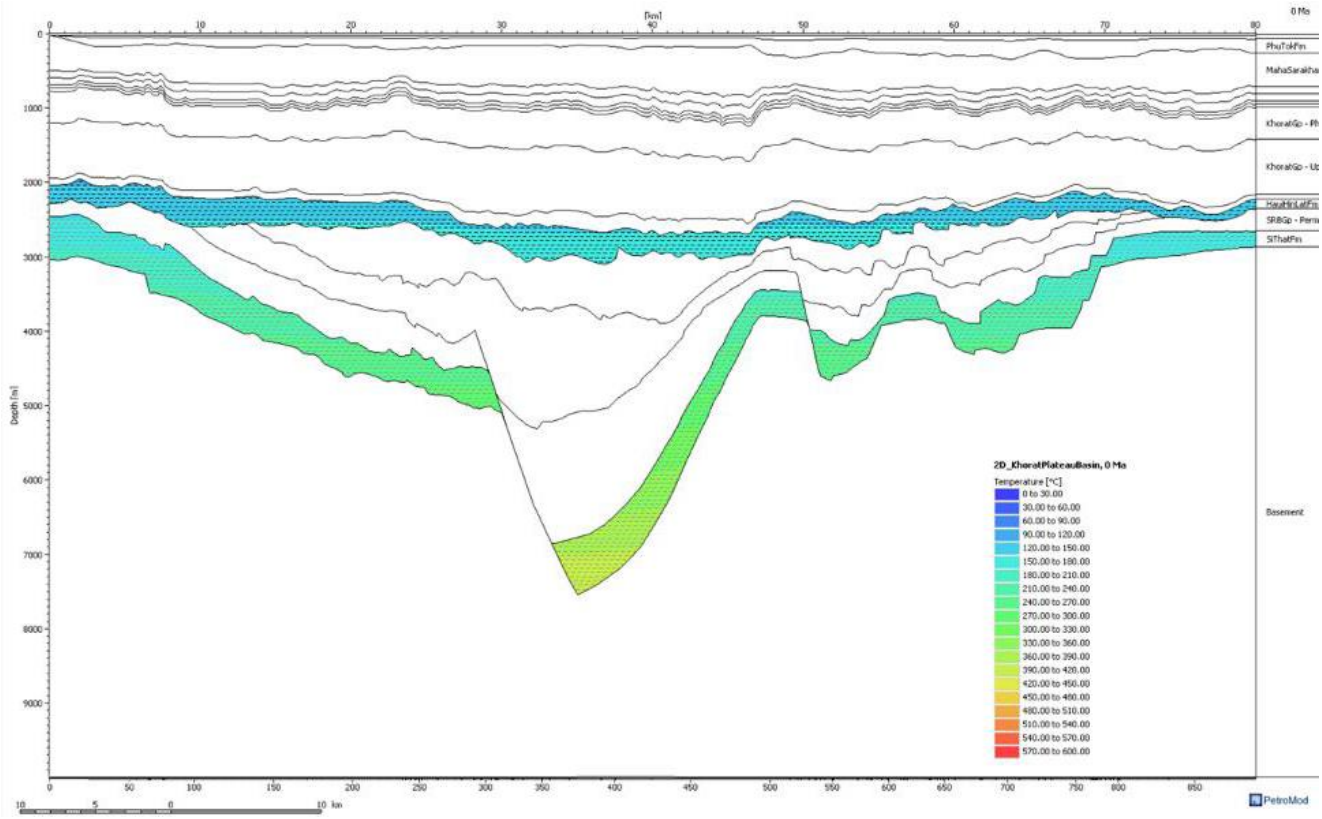


Figure 10. 2D petroleum system model displaying present-day temperarature

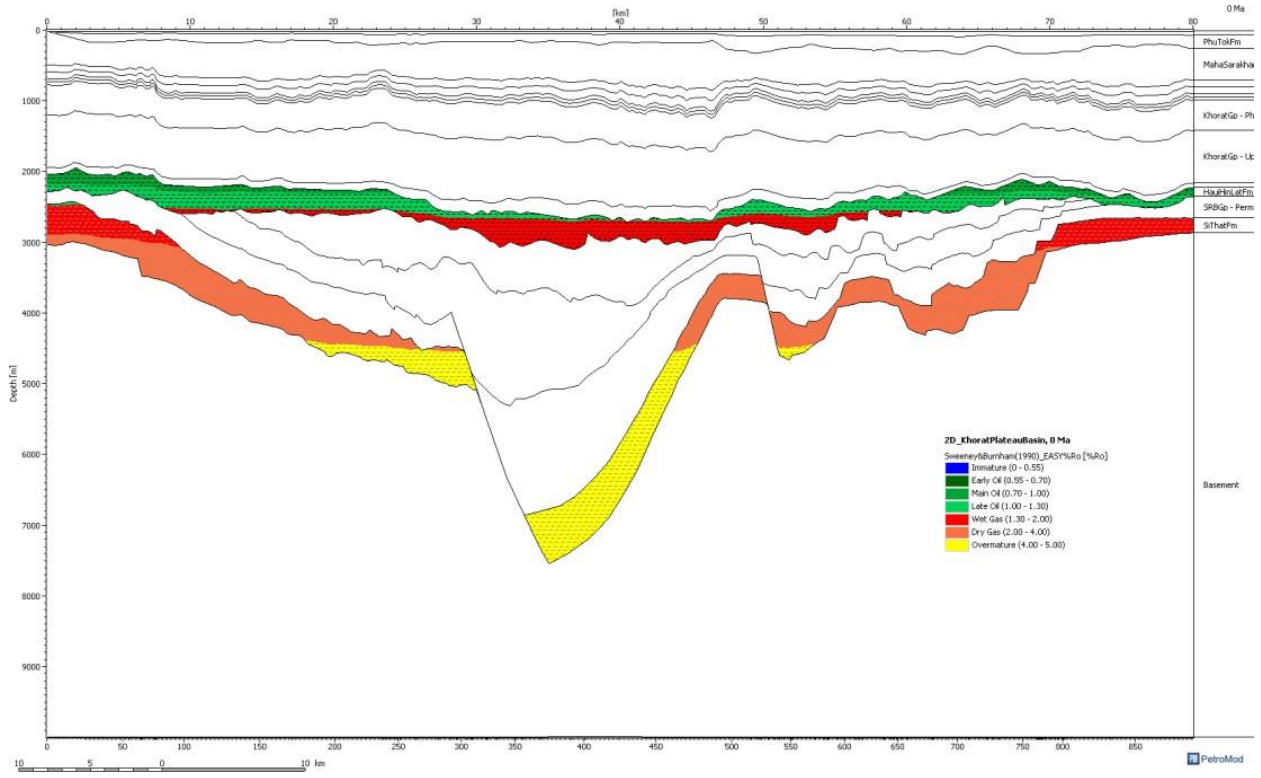


Figure 11. 2D petroleum system model displaying maturity - Sweeny&Burnham

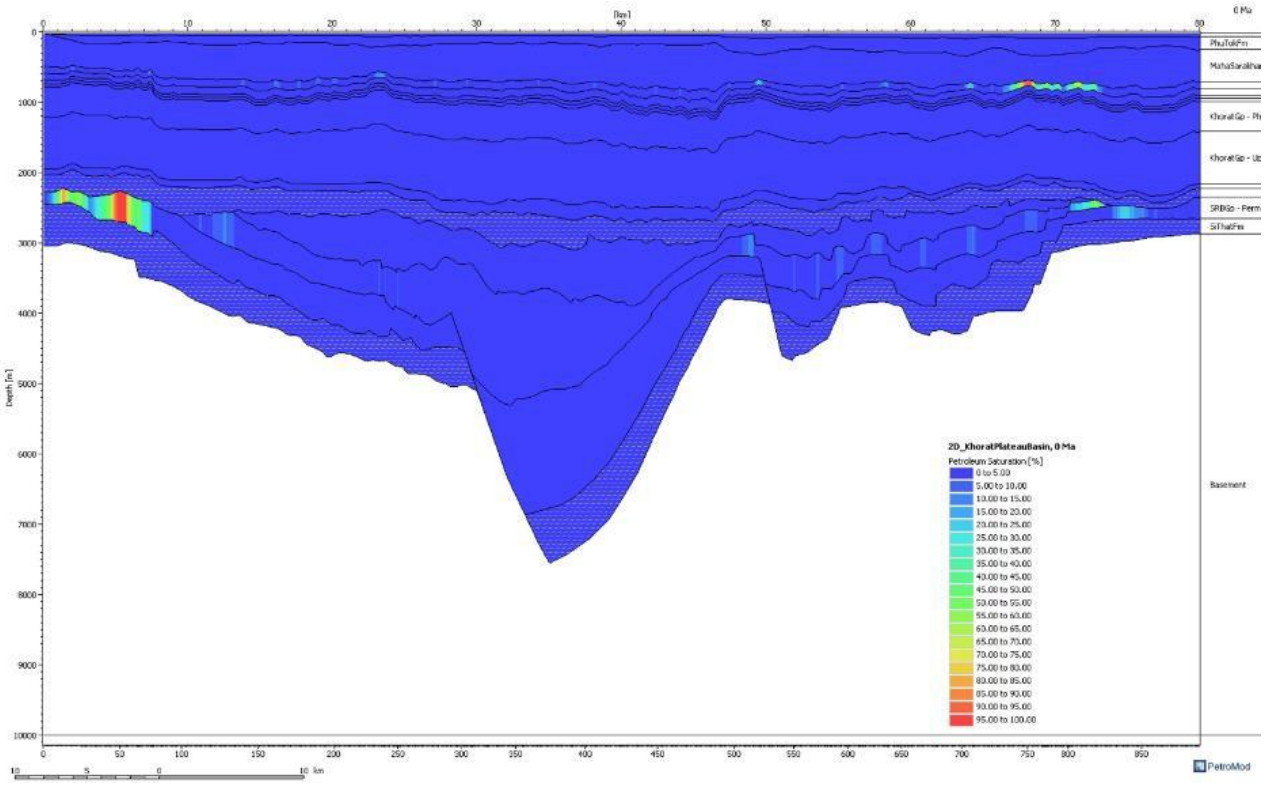


Figure 12. 2D petroleum system model displaying maturity – Hydrocarbon saturation

This is unreliable since the software interpreted leaking point as migration pathway and then interpreted Maha Sarakham Formaiton, as a sealrock. The model results depict that there are possible prospects allowing hydrocarbon migrating to accumulate in there, unfortunately, the migration pathway from Huai Hin Lin source rock to that promising closure is not evidently obvious.

5. Conclusions

Petroleum potentiality of Huai Hin Lat Formation in this study is considered by the integration of geological, geochemical and geophysical data illustrating in geomodelling display. From geological field examination, moderately weathered outcrop is aerially exposed consisting of organic shale, sandstone and interbedded layers with calcite vein filled in fractures. The traces of plant fossils are noticeable indicating terrigenous materials or on-land setting.

Plus. the sedimentary structures tend to be in fluctuated high and low energy environment which can optimistically be anticipated as fluvial and lake deposit, respectively. At this point, Huai Hin Lat Formation seems promising to act as a potential source rock deposited in a place where is plenty of plants and influenced by fluvial sedimentation which can provide type III kerogen and generate petroleum gas later. However, the geochemical results are partially agreed with kerogen quality, meanwhile, hydrocarbon quantity was revealed conversely since Total Organic Carbon (TOC) contents, ranging from 0.02 to ~1, are classified as poor to fair for petroleum potential. Maximum Temperature (T_{max}) are not in optimal cooking windows, ranging from 348°C to 545°C, which are mentioned immature and postmature in terms of thermal maturation stage. Vitrinite Reflectance (R_o), ranging from 1.60 to 1.91 % by weight, can be inferred the organic matter maturation scheme as late mature to over mature.

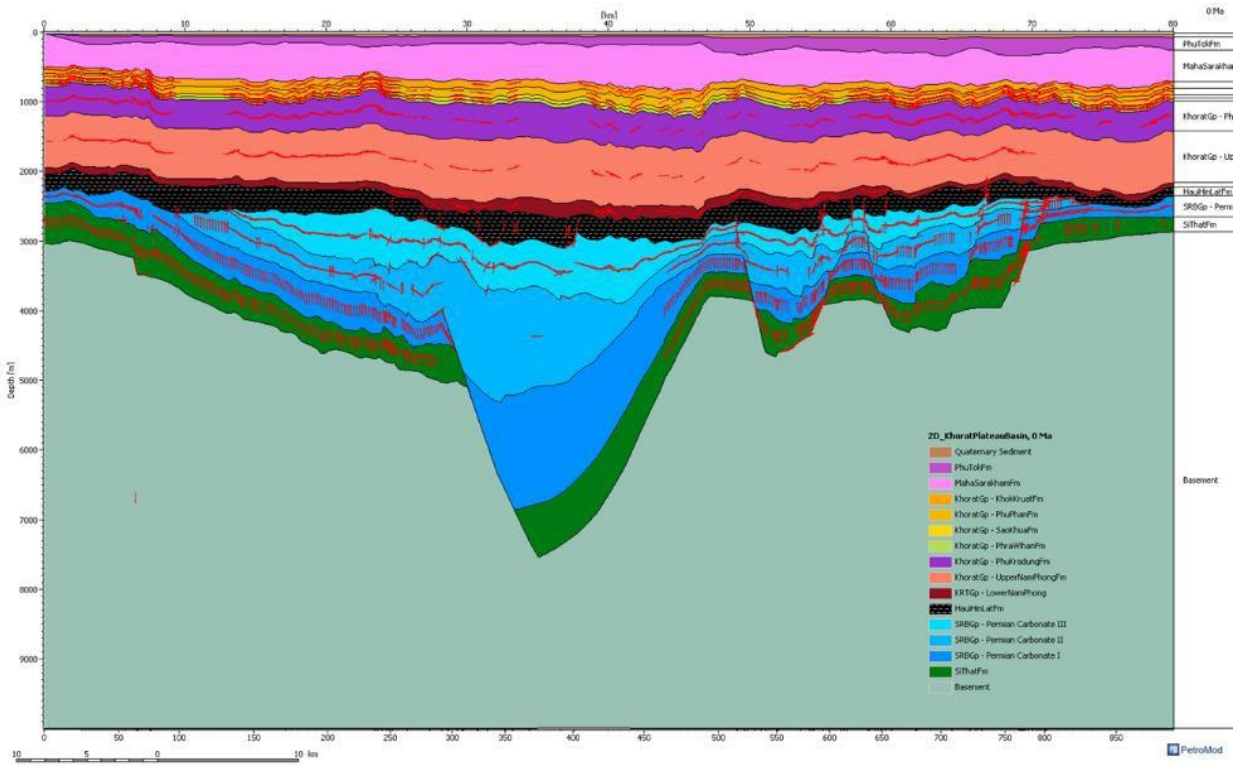


Figure 13. 2D petroleum system model displaying migration with possible pathway

Hydrocarbon generative potential (S1+S2) that in the range of 0.11 to 1.61 mg HC/ g rock. Low Hydrogen Indices (HI) and high Oxygen Indices (OI) are tried to define kerogen type by plotting Pseudo Van- Krevelen diagram. Analyzed samples are found in kerogen type III (gas-prone) and IV (none petroleum potential). Bitumen contents fall in very low range of 19.81-79.94 ppm EOM which are agreed with low TOC contents mentioned above. Biomarker plot suggests paleo- depositional environment of Huai Hin Lat Formation as terrestrial environment where is very high oxidizing area.On the purpose of recapitulation, Huai Hin Lat Formation deposited in terrestrial setting, estuarine or lacustrine environment after rifting events occurred in Indosinian I Orogeny process. It possesses rather low to fair hydrocarbon potentiality in many aspects. For hydrocarbon generation, it gives kerogen type III – gas prone provision. Regarding hydrocarbon qualification, Huai Hin Lat Formation is less promising due to low organic content and high level of maturity. Since it is categorized in postmature stage which mostly is dry gas, hydrocarbon can migrate in case of having reservoir overturn, however, there is no evident of migration from Huai Hin Lat Formation to reservoir (Permian Saraburi Group) in resulted model for this study due to variable assumptions which caused a wide uncertainty. Huai Hin Lat Formation is decided to be low hydrocarbon potentiality.

6. Recommendations

This is the preliminary study of Khorat Plateau model based on the very limited conditions in the aspect of obtaining the sufficient data. To mitigate the errors that can possibly be occurred in each modelling procedure, well data is strongly recommended to possess prior to performing modelling in the next future research.

7. Acknowledgement

This research would not have been complete without many helps from patrons. I would like to express my sincere appreciation to ones involving in this thesis. Firstly, I would like to show up my thankfulness to Assistant Professor Piyaphong Chenrai, Ph. D., my thesis advisor for giving excellent advice, guidance, suggestions throughout working processes. My appreciation includes the committee of Petroleum Geoscience Program, Department of Geology, Chulalongkorn University forproviding the valuable scholarship throughout the academic year.

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