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Present-Day Two-Dimension Maturity History Modelling of Source Rocks from the Central Region of the Andaman Sea Back Arc Depression

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Abstract: Basin modelling is an essential research tool that aids geologists improve the description and analysis of subsurface activity. The central region of the Andaman Sea back arc basin is a potential oil and gas prospect. Herein, two-dimension present-day maturity models are constructed from four seismic sections of the study area using Basin Mod™ software (Platte River Associates, Inc. of USA). Designated study areas are the South to North Moattama Basin, western Moattama to the Mergui Shelf, Western to Eastern Moattama basin centres through Eastern Moattama basin centre to the Eastern section of Mergui basin and Eastern Andaman Sea Basin to Western Mergui Basin. The two-dimension (2D) maturity models are generated from known data burial and geothermal data. Vitrinite Reflectance (Ro%) which is the main variable in determining source rock (s) maturity showed that the source units were within the oil (0.5% ≤ Ro ≤ 1%) and gas (1.3% ≤ Ro ≤ 4.5%) and had commenced generation of some quantities of hydrocarbons. Data analyzed revealed that most portions of the Oligocene and Lower Miocene shales source units in all study areas buried below 2000 m are matured to generate oil and / or gas. The outcome of modelling also indicated that source units from the Moattama Basin center and the Mergui Basin were mostly matured to produce some form of hydrocarbons, principally gas or dry gas. However, no oil expulsion into limestone reservoirs was observed; only gas or dry gas.

Keywords: Maturity History Model, Andaman Sea, Vitrinite Reflectance, Back Arc Depression, Basin Modelling, Seismic Profile, Oil and Gas Windows

1. Introduction

Basin modelling has been used in various studies by researchers to evaluate source rock maturation, generation and expulsion, just to mention a few [1-3]. The central region of the Andaman Sea back arc depression cuts across three major basins namely: Andaman Sea Basin, Moattama Basin and Mergui Basin. Selected seismic cross-sections of study areas are: South to the North Moattama Basin; West to East Moattama Basin up to the Mergui shelf; Western to Eastern Moattama basin centres through to the Eastern section of Mergui basin; and a section from Eastern Andaman Sea Basin to Western Mergui Basin [4].

Prior research done by Polachan and Racey in the Mergui Basin conveyed that large Tertiary basin in the Andaman Sea has suitable structures to be a potential petroleum region, but exploration wells discovered only small quantities of oil and natural gas. In recent past, the deep-water orientation and restriction on available data had made the Mergui basin unfavourable for petroleum exploration by petroleum companies. Also, during the 1998 to 1999 period, Kerr-McGee (Thailand) Limited and partners provided drilling data that showed this basin had suitable structures for reservoir rocks and contained good source rocks, nonetheless, there was no commercial petroleum accumulation discovery [5]. Furthermore, data made accessible by Information Handling Services Energy (IHS Energy) reveals that there's still a significant unexplored area within the Moattama basin. Quaye and Xu averred from their research that Oligocene source rocks were mature and generated considerable quantities of oil and gas, however, there was no recorded expulsion of gas from Oligocene source units (Table 3). Certain portions the Lower Miocene source units expelled substantial amounts of gas into reservoirs.

The quality and potentiality of source rock (s), and maturation of organic matter are essential in the analysis of petroleum systems [6]. In this study, basin modelling of source rocks is utilized to calculate the timing of hydrocarbon generation and/or expulsion. This study seeks to affirm or otherwise the prospects of basins considered in this research. Through construction of models, specific areas with good source rocks and structural traps but have no hydrocarbon accumulation may better be understood and may improve the likelihood of commercial petroleum accumulation discovery [7]. It may decrease the cost of exploration within the study areas.

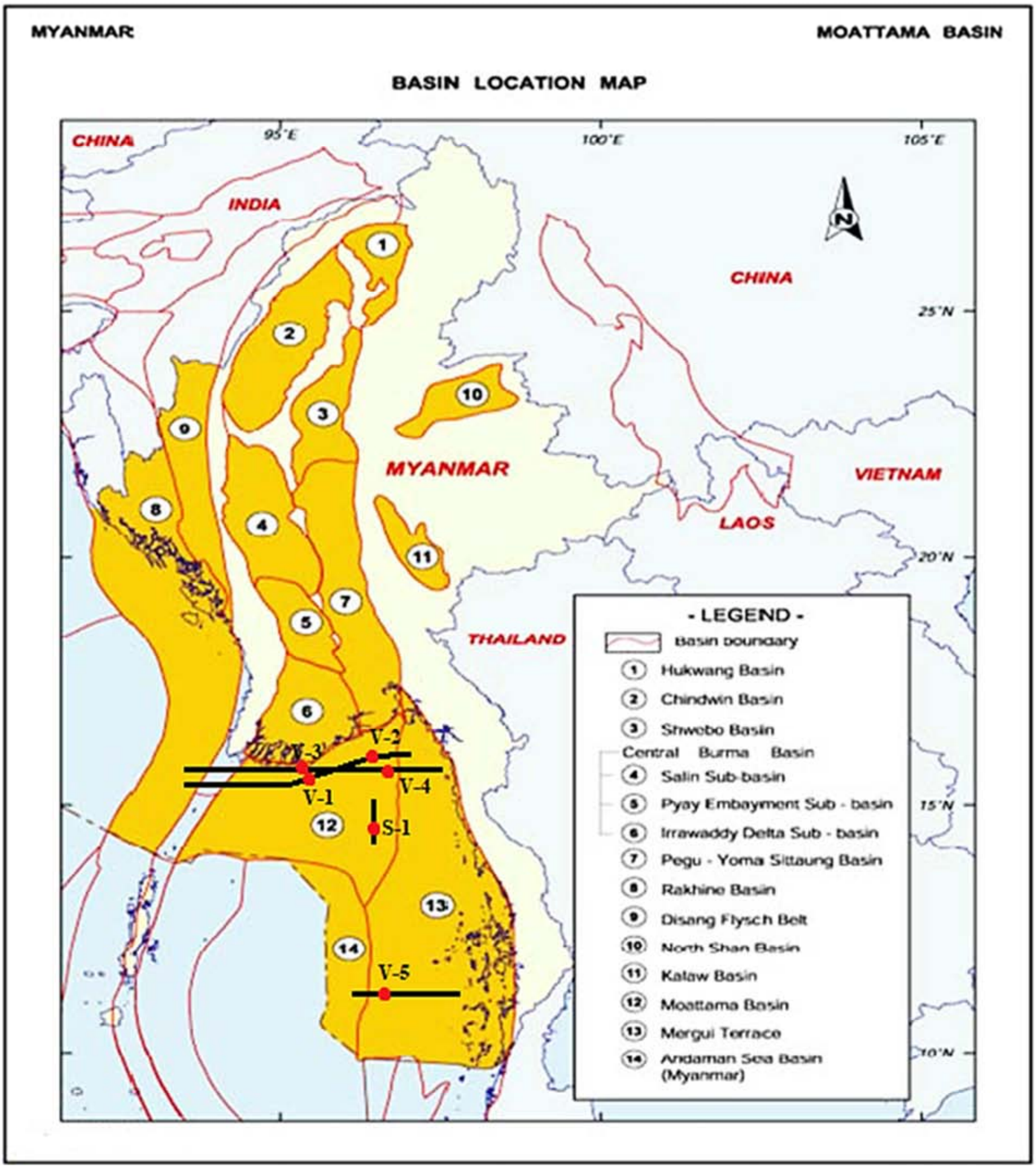

Figure 1. *Map of study areas showing basins, well locations and four seismic lines; image source: Information Handling Services (IHS) Energy.*

2. Geological Setting and General Stratigraphy

The Andaman Sea Basin is about 1,250 km from Myanmar to Sumatra and was developed by the oblique convergence of the Indian Oceanic and South East Asian Tectonic plate boundaries. This event began in the early Cretaceous and has prolonged to the present day. The study area cuts across a wide bathymetric range, from extremely shallow water to over 3500 m. In addition, there are several areas with high relief and sudden alterations in depth. The region has structural and tectonic complexity with many steep dips, the angle and direction of which changes strikingly within short distances. Source units generally comprise shale and mudstones from the Late Cretaceous to Oligocene with Total Organic Carbon (TOC%) of up to 5.2% reported onshore in the Andaman Islands and outlying offshore areas [8].

The evolution of the Moattama Basin is directly linked with oblique convergence of the Indian and Myanmar tectonic plates and opening of the Andaman Sea. The Moattama basin remained a portion of the Tethys Sea during most of the Late Cretaceous in an open marine setting. This continued until the Tethys Sea was totally closed in the north during Middle Eocene due to the Indian plate northeast boundary subduction beneath the Myanmar Plate. The Outer Non-Volcanic Arc was uplift became the accretionary wedge at latter period of the Eocene. There was quick subsidence at the western margin of basin depocentre with deposition of deep marine sediments. The eastern part of the basin remained submerged, with constant sediment supply from the Shan-Thai Craton. By the early Oligocene, volcanic activity began in the basin extending to the Late Miocene and resulting in the creation of the Inner Volcanic Arc that partitioned the basin into a Fore-arc trough on the west and a Back-arc trough on the east. The basin evolved into a prodelta by late Miocene and gradually became a delta situated in front of the Irrawaddy Delta System. The Oligocene to Middle Miocene shales and claystones form main source units, with the Oligocene shales (Table 1) being the major. Eocene shales remain older potential source rocks with Upper Miocene (Table 1) prodelta claystones also potential source rocks. Chances of being mature may occur in the deeper part of the basin where they are buried at appropriate depths [9].

Table 1. *Combined stratigraphy tables comprising one-dimension data from five wells in study areas; modified after Quaye and Xu.*

Well Name	Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thickness (m)	Lithology	Organofacies / Kerogen	TOC (%)	Petroleum System Events
S-1	Lower Miocene	F	23	6951	3865	Shale	Type III (BMOD 1-D)	1	Source/Reservoir
	Oligocene	F	28	10816	770	Shale	Type III (BMOD 1-D)	1	Source
V-1	Lower Miocene	F	23	2374.18	3268.5	Shale	Type III (BMOD 1-D)	1	Source/Reservoir
	Oligocene	F	28	5642.68	461.81	Shale	Type III (BMOD 1-D)	1	Source
V-2	Lower Miocene	F	23	3764.4	4886.7	Shale	Type III (BMOD 1-D)	1	Source
V-3	Lower Miocene	F	23	2533.37	678.56	Shale	Type III (BMOD 1-D)	1	Source
	Oligocene	F	28	3211.93	2892.56	Shale	Type III (BMOD 1-D)	1	Source
V-4	Lower Miocene	F	23	2219.19	816.85	Shale	Type III (BMOD 1-D)	1	Source
	Oligocene	F	28	3036.04	1944.04	Shale	Type III (BMOD 1-D)	1	Source
V-5	Lower Miocene	F	23	902.77	539.55	Shale	Type III (BMOD 1-D)	1	Source
	Oligocene	F	28	1442.32	1337.69	Shale	Type III (BMOD 1-D)	1	Source

The Mergui basin is a N-S trending half graben that formed from rifting of the Andaman Sea basin in the Late Tertiary due to subduction of the Indian Ocean Plate underneath the South East Asian Plate at a rate of 6 to 7 cm per year [10]. The Mergui basin is divided into 3 sub-basins: the western, eastern and northern sub basins. The eastern Mergui sub-basin as compared to the western Mergui sub-basin is wider and contains thicker sediments in west and south. The Ranong Trough and Similan Basin are two smaller basins separated by the Ranong Ridge. Noticeable faults in Mergui Basin are normal and strike-slip faults. In the Mergui Fault Zone (dextral wrench fault) is the main strike-slip fault which is NNW-SSE oriented and is connected to opening of the basin [11]. Source rocks documented in the basin are the Thalang, Trang, Kantang and Yala Formations, however, the Thalang, Trang and Kantang Formations are not mature. The Yala Formation remains the only mature source unit.

The stratigraphy chart in figure 2 provides adequate information on parameters such as begin and end ages, Formation and lithology, just to mention a few, and are substantiated in literature cited as references in this study. The principal formations from old to new with begin ages are Oligocene (28 Ma), Lower Miocene (23Ma), Middle Miocene (17Ma), Upper Miocene, (10 Ma), Pliocene (5 Ma) and Pleistocene (3 Ma). The main source rocks are Oligocene and Lower Miocene shales whilst limestone and sandstone makeup reservoir rocks. Siltstone and shales form the seals.

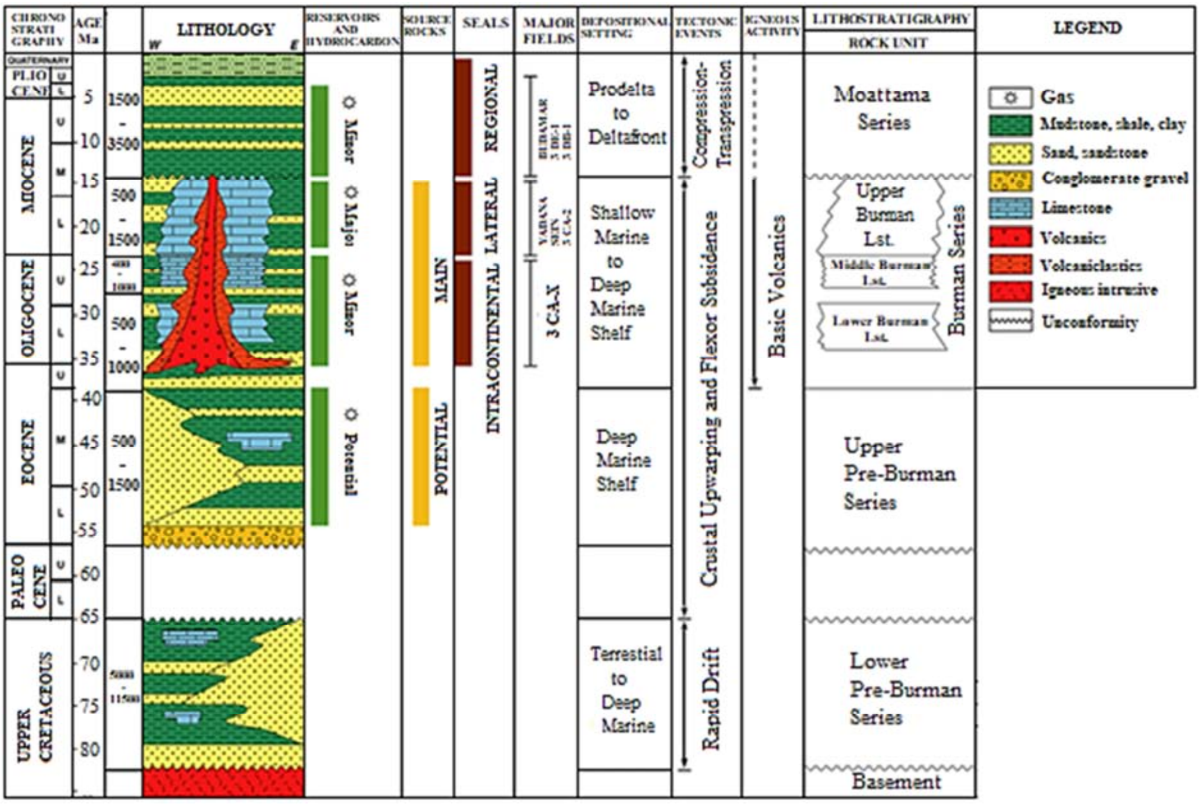

Figure 2. *Detailed stratigraphy of study area; image source: Information Handling Services (IHS) Energy.*

3. Method and Materials

One-dimension modelling data of four geo-seismic profiles of study areas considered was input into the Basin Mod ™ software developed by Platte River associates, USA to construct two-dimension maturity models. These include burial, heat flow, geothermal and maturity data retrieved from five wells (Table 1). For instance: the incorporation of interpreted 2D vintage seismic data together with well information to create a consistent numerical model has been carried out in other studies [12].

3.1. Heat Flow Parameters

The Late Oligocene-Early Miocene and Miocene rifts were the two principal rifting events that controlled heat flow cycles of the source rocks within the study area (Figure 3; Table 2). Present-Day heat flow is 60 mW/m^2. In Figure 3, the Late Oligocene-Early Miocene rift happened between 30 my and 25 my, whilst the Middle Miocene rift occurred between 15 my and 10 my.

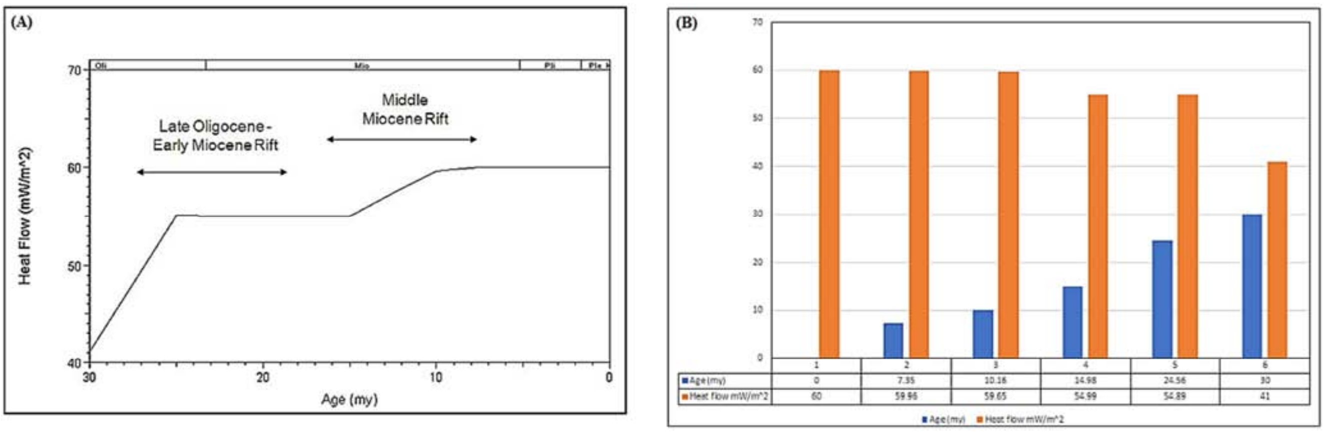

Figure 3. *Heat flow history of the two major rift systems of study areas. (A) Heat flow chart; (B) 2D clustered column chart.*

The thermal history calculated in Basin Mod two-dimension (2D) utilizes the transient heat flow (Figure 4B) method. Heat Flow entered as a numerical value is applied at the bottom of the sediment column. Heat flow can be constant or can be varied laterally and temporally. Heat flow values are input at XsecX positions shown by the red arrows (Figure 4A). Model calculations utilize the values which are interpolated between points. Values are entered for every age and interpolated between ages. The thermal transfer may not be in equilibrium during the evolution of a basin as a result of a number of geological activities. Such activities would be abrupt basement subsidence associated with large quantities of sediment deposition within a short period, quick uplift followed by substantial erosion, or quick heat flow alteration such as that caused by the onset of a rifting event.

Table 2. *Heat flow parameters of rifting events described in Figure 3.*

Age	Heat flow
(my)	mW/m^2
0	60
7.35	59.96
10.16	59.65
14.98	54.99
24.56	54.89
30	41

This manner of activities will cause the basin to exit its state of thermal equilibrium at a certain time period. To describe the effects these events, have on thermal history, a transient heat flow model should be used. In an instance of non-equilibrium, some quantity of heat energy is consumed in elevating the temperature of sediments into thermal equilibrium. Heat flow input is, therefore, unequal to heat flow output. The heat capacity value of the sediments, rate of sedimentation, just to mention a few have an influence on the extent of modifications in heat flux. Greater heat capacity of sediments tend to have a corresponding effect on heat energy absorption. Elevated rates of sedimentation (> 100 m/my) supposes a huge quantity of sediment deposition, and therefore needs a greater amount of heat energy to effect temperature equilibrium [13].

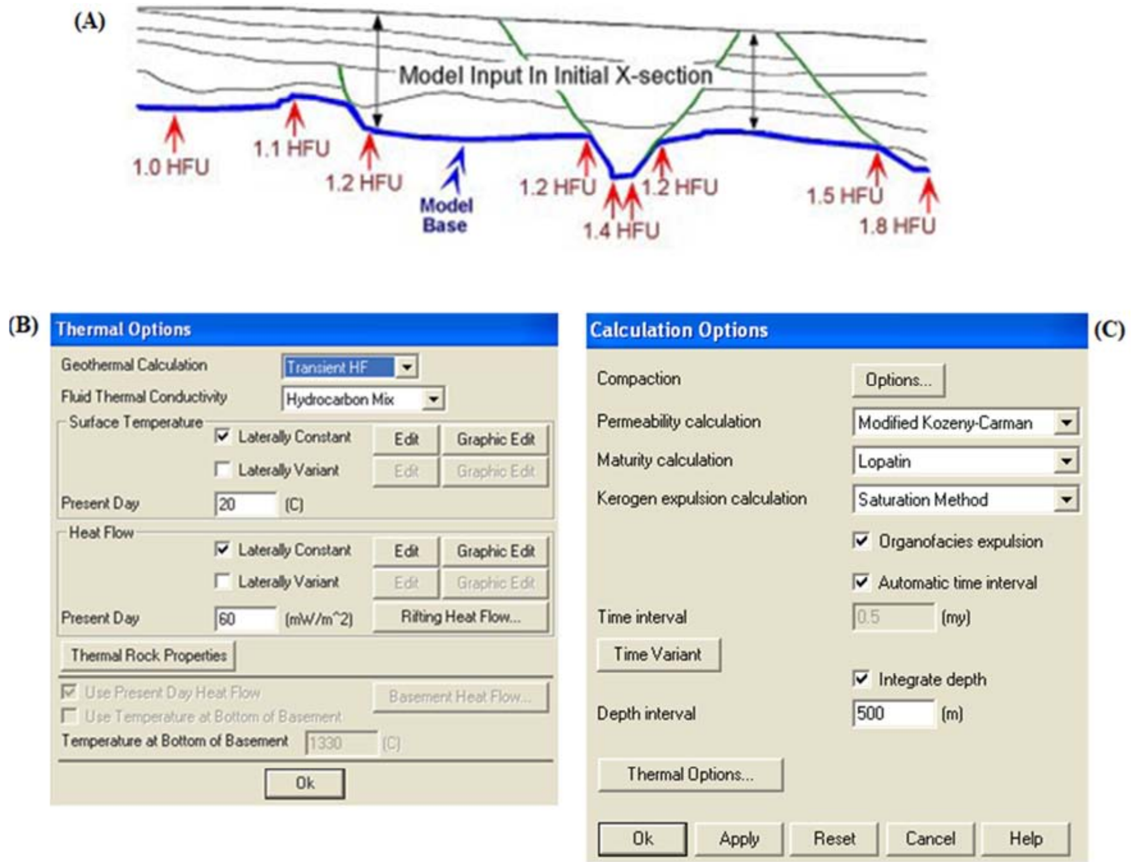

Figure 4. *Thermal and maturity parameters utilized in modelling (A) Generalized heat flow at Xsec-X locations (B) Geothermal calculation details showing present-day temperature (20 °C) and present-day heat flow (60 mW/m^2); (C) Maturity calculation options showing the Lopatin TTI method employed in this study.*

3.2. Maturity Calculation

A number of methods are used to estimate maturity of source units, but this study employs and uses the Lopatin TTI method (Figure 4C). The Time Temperature Index (TTI) method for calculating maturity was developed, and is the application of the supposition that maturity reaction doubles for every 10° C increment in temperature [14]. This simple method has been commonly used in basin modelling since its inception [15]. The TTI method furnishes agreeable forecast capabilities and direct empirical relationship to vitrinite reflectance (Ro), in addition to other measured maturity indicators such as Thermal Alteration Index (TAI) and Maximum Temperature (TMAX).

3.3. Seismic Profiles

Figure 5 exhibits four seismic profiles of study areas selected for construction two-dimension (2D) maturity models. Also displayed are their respective Wells. Well S-1 remains the only true Well whilst V-1, V-2, V-3, V-4 and V-5 are pseudo Wells drawn for the purpose of this study. These wells provided valuable one-dimension (1D) burial and geothermal data that enabled construction of two-dimension (2D) maturity models.

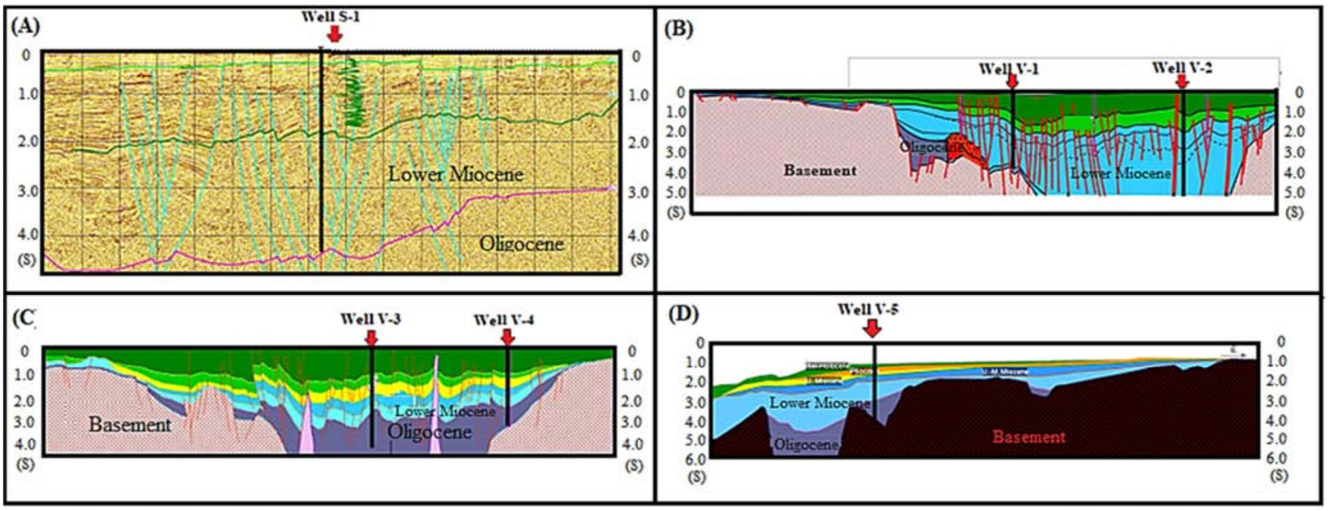

Figure 5. Four seismic profiles showing wells. (A) South to North of Moattama Basin showing well S-1; (B) Western Moattama to the Mergui Shelf showing pseudo Wells V-1 and V-2; (C) Western Moattama to eastern section of the Mergui Shelf showing pseudo Wells V-3 and V-4; (D) Eastern Andaman Sea Basin to Western Mergui Basin showing pseudo well V-5.

4. Result & Discussion

This section outlines the results and discussion obtained from two-dimension (2D) maturity modelling of study areas. These models represent the contemporary description of source units maturity studied.

4.1. Present-day Moattama Basin South to North Vitrinite Reflectance (Ro) Maturity

Figure 6 indicates that Oligocene and Lower Miocene source rocks are mature and are positioned specifically at certain points within the maturity windows and at particular depths. It is crucial to reiterate that the entire region from the South-North seismic line is mature to produce hydrocarbons, but at varying maturity windows. The northern section at 10000 m and below shows very high maturity with vitrinite reflectance values estimating about 4.5%. On a conventional (Ro%) scale, most portions of the Oligocene source rock would produce gas (dry gas). Vitrinite reflectance (Ro%) exhibits values between 4% and 4.5%, which falls within the gas window. The southern section of Lower Miocene shale situated between 5000 m and 6500 m lies within the oil window (0.5% ≤ Ro ≤ 1%) and is likely to produce oil. Below 6500 m maturity records between 2% and 4.5% which is in the range of the gas window (1.3% ≤ Ro ≤ 4.5%).

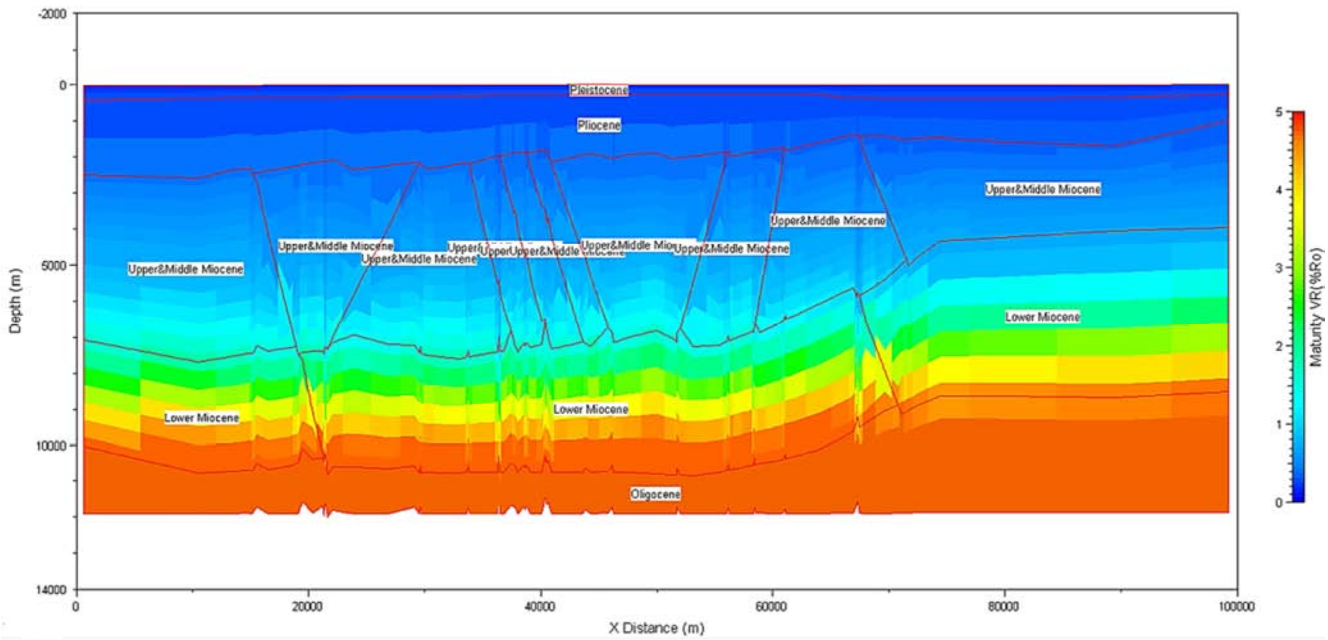

Figure 6. Present-day 2D Moattama Basin South to North Vitrinite Reflectance (Ro%) maturity profile.

4.2. Present-day West to East Moattama Basin to the Mergui Shelf Vitrinite Reflectance (Ro%) Maturity

The Oligocene shale formation is truncated mid-way by a dominant Lower Miocene shaly formation as shown in Figure 7. Below 3000 m, Oligocene shale shows vitrinite reflectance (Ro%) between 2% and 4.5% Ro. Lower Miocene shales from 2000 to approximately 4200 m exhibit vitrinite reflectance in the oil window; (0.5% ≤ Ro ≤ 1.3%). From 4200 m downwards, the gas maturity window (1.3% ≤ Ro ≤ 4.5%) is more conspicuous.

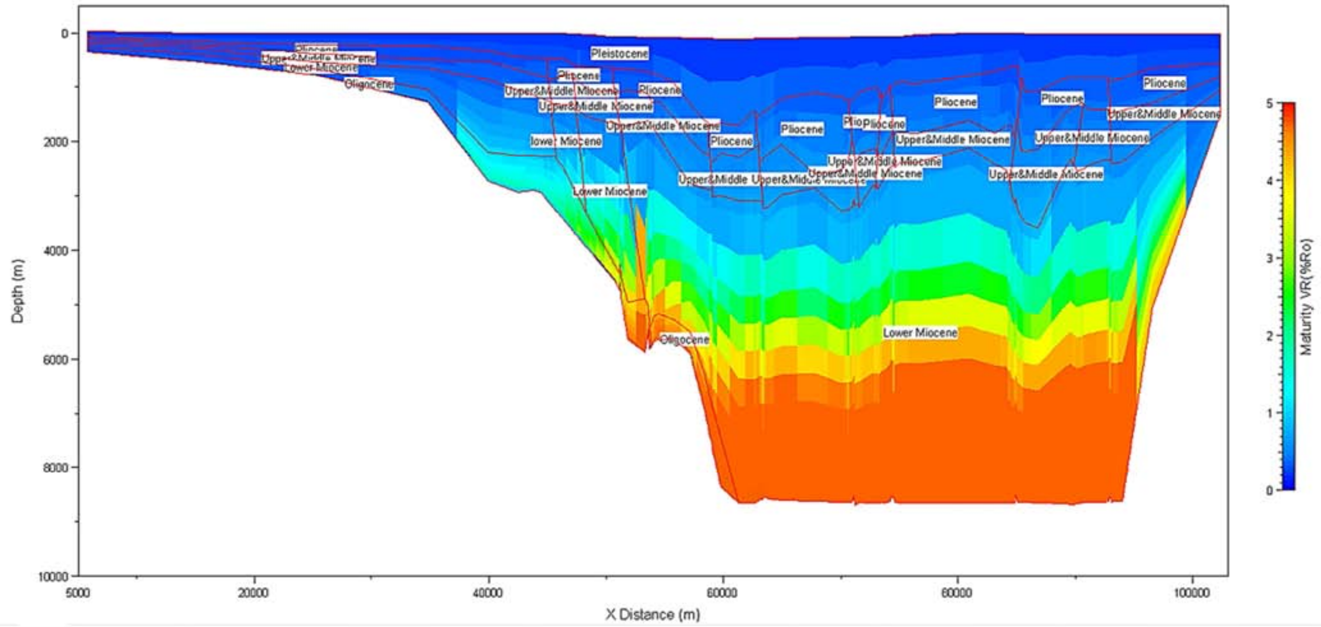

Figure 7. *Present-day 2D West to East Moattama Basin up to the Mergui Shelf Vitrinite Reflectance (Ro%) maturity profile.*

4.3. Present-day West to East Moattama Basin Centre to the Eastern Mergui Basin Vitrinite Reflectance (Ro%) Maturity

In Figure 8, the Lower Miocene source rock generally ranked within the scope of the oil window (0.5% ≤ Ro ≤ 1%) and is mature to produce mostly oil. Apart from the western Moattama Basin margins (basement high) and eastern Mergui Basin margins (basement high) that cuts across under mature (0.04% ≤ Ro ≤ 0.5%) hydrocarbons, shales deposited at the western Moattama basin center are mature to produce oil and/ or gas at specific depths.

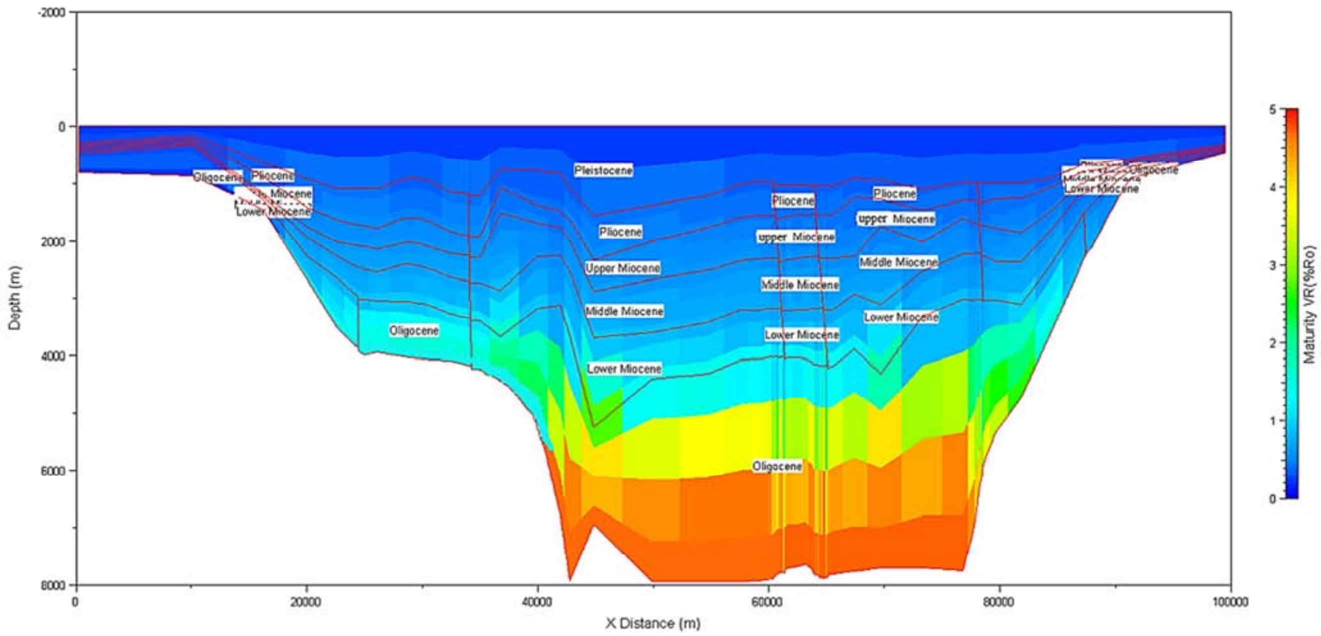

Figure 8. *Present-day 2D West to East Moattama Basin Centre to the Eastern Mergui Basin Vitrinite Reflectance (Ro%) maturity profile.*

Oligocene shales buried below 4000 m and located within the western Moattama basin centre indicate vitrinite reflectance between 2% and 4.5%. This is within the scope of the main gas generation and dry gas maturity windows. Margins of the study areas display either under mature shales or mature shales in the range of early oil maturity window (Ro = 1.3%).

4.4. Present-day Eastern Andaman Sea Basin to Western Mergui Basin Vitrinite Reflectance (Ro%) Maturity

A section of the Oligocene source formation within this study area is truncated by the basement because the structural style is basement-involved and not detached, and the formation heat flow is controlled by basal heat flow. On the eastern boundary of the Andaman Sea Basin, Oligocene source units depict vitrinite reflectance from 2.3% to 2.8% (dry gas generation). From the eastern regions of the Andaman Sea Basin to the eastern regions of the Mergui Basin, Oligocene shales is within the range of the oil window (0% ≤ Ro ≤ 1%). At the western regions of the Andaman Sea Basin between 2600 m to 6600m, Lower Miocene shales show maturity between 0% and 1.3%. From the eastern Andaman Sea Basin to the western regions of the Mergui Basin, shales maturity is less than 1%.

Table 3. *Hydrocarbons generation and expulsion in source rocks of various Wells; modified after Quaye and Xu.*

Well Name	S-1	V-1	V-2	V-3	V-4	V-5
Present-day Oil generated (mg/g TOC)						
Lower Miocene Source Unit	43	nil	33	17	15	nil
Oligocene Source unit	50	48	nil	43	42	23
Present-day Gas generated (mg/g TOC)						
Lower Miocene Source Unit	130	1	87.5	35	25	
Oligocene Source unit	132	122.5	nil	126	116	49
Present-day Oil expelled (mg/g TOC)						
Lower Miocene Source Unit	nil	nil	nil	nil	nil	nil
Oligocene Source unit	nil	nil	nil	nil	nil	nil
Present-day Gas expelled (mg/g TOC)						
Lower Miocene Source Unit	76	2	108	nil	nil	nil
Oligocene Source unit	90	43	nil	33	nil	nil

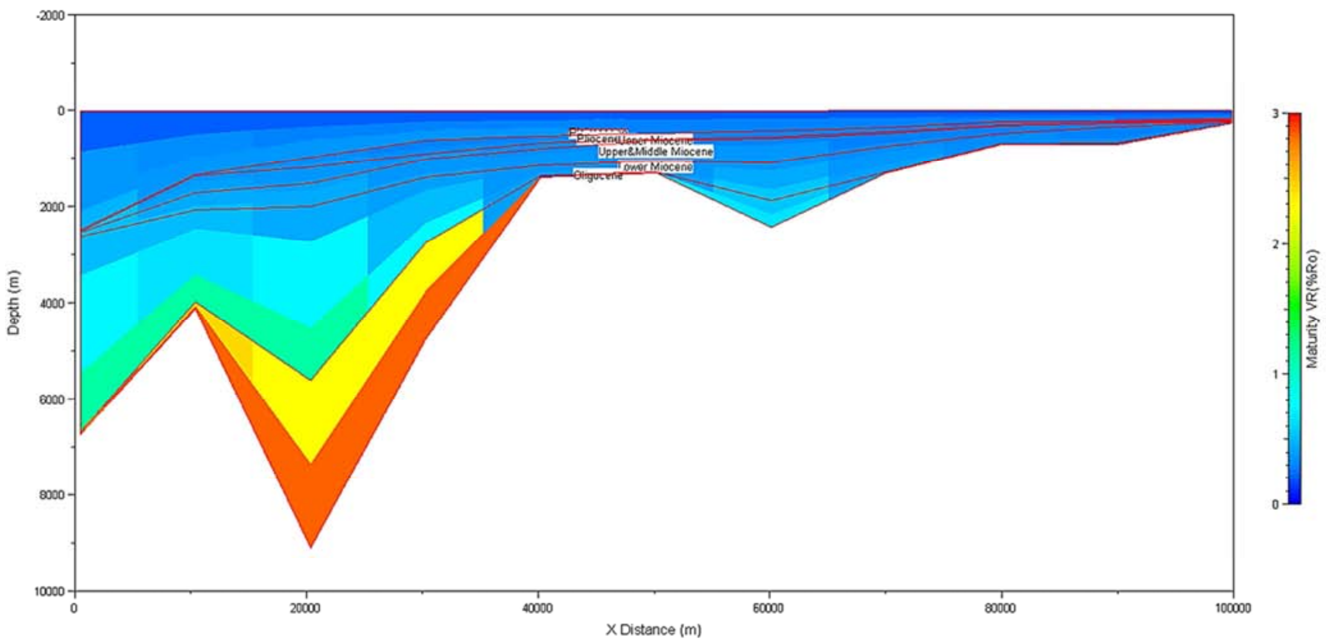

Figure 9. *Present-day 2D Eastern Andaman Sea Basin to Western Mergui Basin Vitrinite Reflectance (Ro%) maturity profile.*

5. Conclusions

Four seismic sections and wells data were utilized to construct 2D maturity models of designated study areas located within the central region of the Andaman Sea back arc depression. The results of modelling revealed that source rocks from the Moattama Basin center and the Mergui Basin were mostly matured to produce some form of hydrocarbons, principally gas or dry gas. Wells data indicated that most portions of source rocks buried below 2000 m in all study areas are matured to generate oil and / or gas. There was no record of oil expulsion into limestone reservoirs; only gas or dry gas, however, this condition may not be prevalent in all designated study areas. The Oligocene source rock formation remained the major source unit, after that Lower Miocene shales.

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