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One Dimensional Evolution History Modelling Of Source Rocks in the Central Andaman Sea Back Arc Depression

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Abstract

The back arc basin located in the central Andaman sea area is said to contain good source rocks and, therefore, a prospective area for hydrocarbon exploration. One dimension (1D) evolution modelling, which includes the burial, geothermal and maturity histories of five wells located in geo-seismic cross-section profiles of the back arc is constructed.

Keywords: Geothermal, Maturity, Backarc Basin, Basin modeling.

Introduction

The central Andaman Sea back arc depression encompasses three basins namely the Andaman Sea, Moattama and the Mergui Basins. This study involves specifically four geo-seismic cross-sections, firstly of Moattama basin which runs from the south to the north; secondly a section which runs from the western Martaban (Moattama) basin through the Eastern Martaban (Moattama) Basin up to the Mergui shelf; thirdly a section of the western basin centre of the Moattama basin through the Eastern Basin centre (Moattama basin) up to the Eastern section of the Mergui basin; fourthly, a section from Eastern Andaman Sea Basin to the Western Mergui Basin.

Previous study by Polachan and Racey (1994) especially in the Mergui Basin reported that large Tertiary basin in the Andaman Sea that has appropriate structures to be a potential petroleum field. However, the exploration wells found only traces of oil and natural gas. The limitation in available data and the deep water location of the basin had made the Mergui Basin unfavourable for petroleum exploration by petroleum companies in the past. Drilling data in the Mergui Basin by Kerr-McGee (Thailand) Limited and partners during 1998-1999 revealed that this basin has suitable structures for reservoir rocks and contains appropriate source rocks. However, there was no commercial petroleum accumulation found in this basin [1]. Data available from IHS Energy also reveals that there's still a considerable of unexplored area in the Moattama basin. Basin modelling has been used by the oil and gas industries to study the physical and thermal histories of the petroleum basins

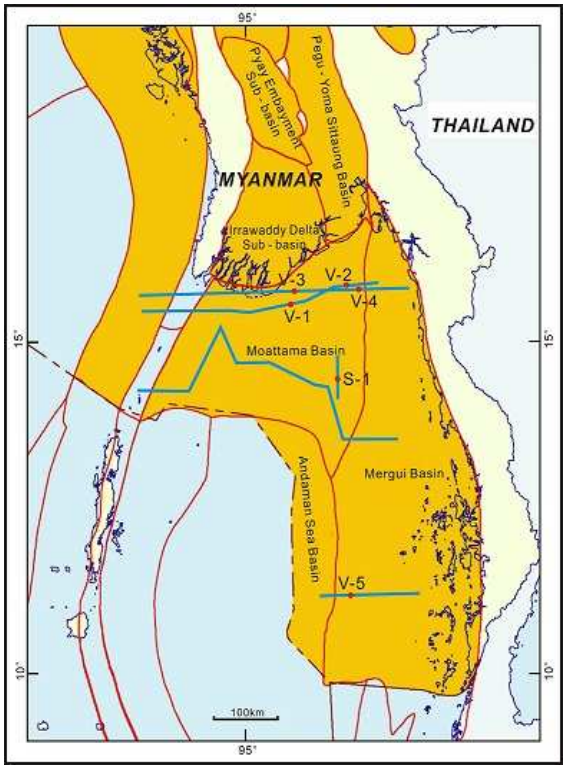


Fig 1: Map showing Wells in study area

The models can be analyzed to estimate the timing of hydrocarbon generation and expulsion. Certain areas that have good source rocks and structural trap but do not have the petroleum accumulation may be due to either (1) the formation of structural trap was after expulsion from the source rock or (2) the occurrence of petroleum migration

(tertiary migration) after petroleum charge. Basin modelling of the central Andaman Sea back arc depression will increase the chances of finding commercial petroleum accumulation and decrease the cost of exploration in this area [2].

Data from one true well, S-1 is used in constructing the Burial, Geothermal and Maturity histories of five other pseudo wells within the central Andaman Sea Back arc depression; V-1, V-2, V-3, V-4 and V-5 respectively.

Parameters/Data used in 1D modelling

Primary data was collected only for study area, the central Andaman Sea back arc depression. These data include stratigraphy charts, seismic sections, heat flow and age of formations, present thickness and lithology. These will be discussed in details in the sub-sections below.

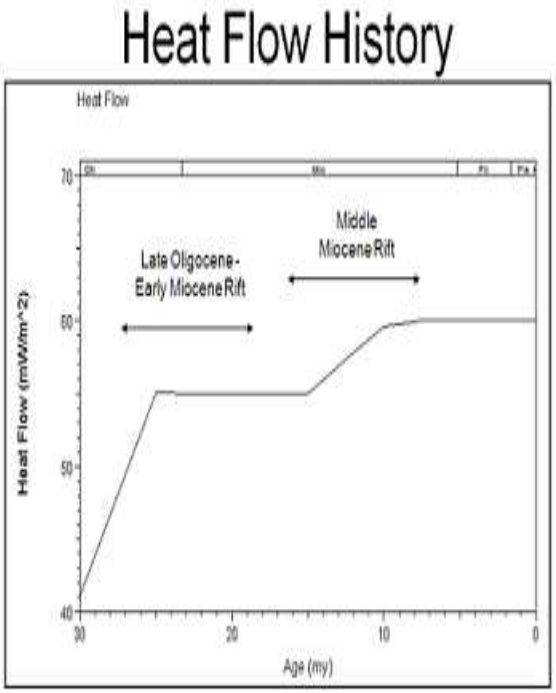


Fig 2: Heat Flow History chart of study area

The Late Oligocene-Early Miocene and Middle Miocene rifts are the two main rifting events that influence the heat flow pattern of the source rock formations within the central Andaman Sea Back arc depression. Present-Day heat flow remains 60mW/m^2.

Start age (My)	End (My)	Rifting Beta	Lithosphere thickness (km)
30	25	2	125
15	10	2	125

Table 1: Rifting events

In Figure 3, the Late Oligocene-Early Miocene rift occurred between 30My and 25My; Middle Miocene rift between 15My and 10My.

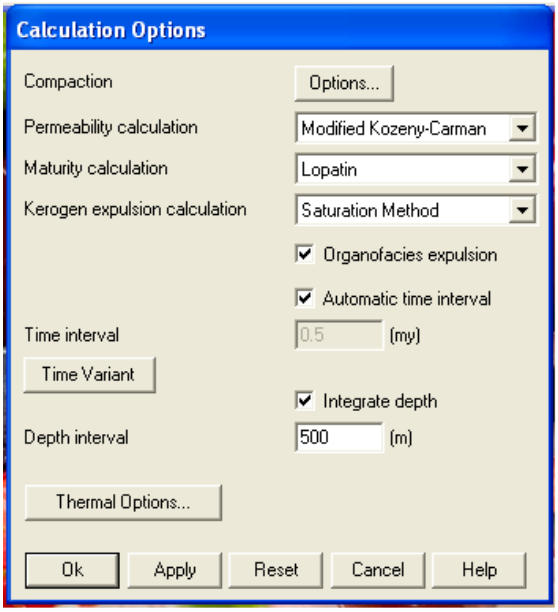


Fig 4: Maturity and Expulsion Options in BasinMod™

The above figure displays maturity calculation set to "Lopatin" method and Kerogen Expulsion Calculation also set to "Saturation Method"

Well Locations in Seismic Profiles

Below are the seismic cross-sections in which various drilled pseudo Wells are located:

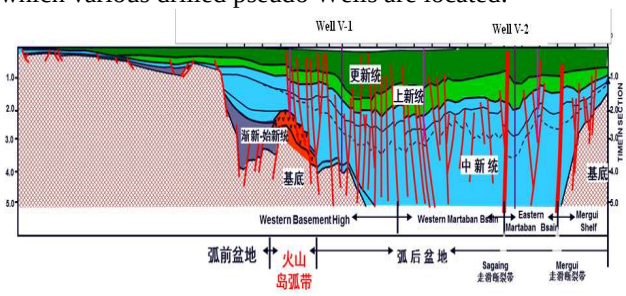


Fig 5: Seismic Cross-section profile from western Moattama to the Mergui Shelf showing pseudo wells V-1 and V-2

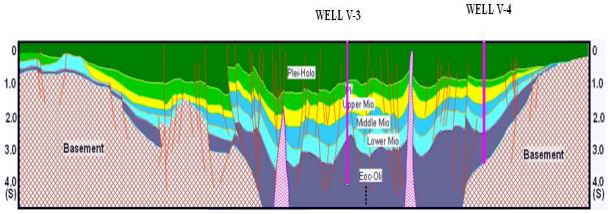


Fig 6: Seismic Cross-section profile from western Moattama to the Mergui Shelf showing pseudo wells V-3 and V-4

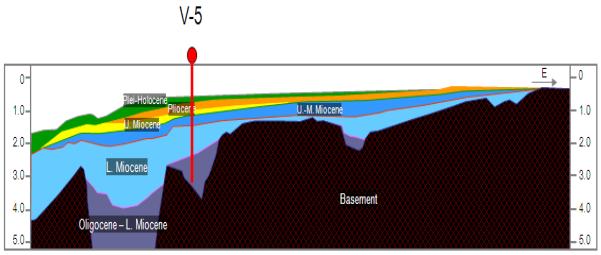


Fig 7: Seismic Cross-section profile from Eastern Andaman Sea Basin to Western Mergui Basin showing pseudo well V-5

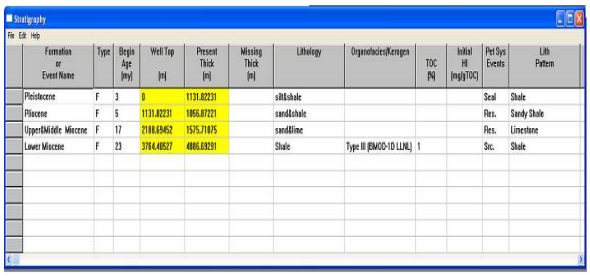
Stratigraphy Tables

The stratigraphy table in Basin Mod 1D allows input parameters such as:

- ✓ Formation or Event Name
- ✓ Type
- ✓ Well Top
- ✓ Present thickness
- ✓ Organofacies/Kerogen
- ✓ TOC (%)
- ✓ Petroleum System Events
- ✓ Lithology & Lithology Pattern

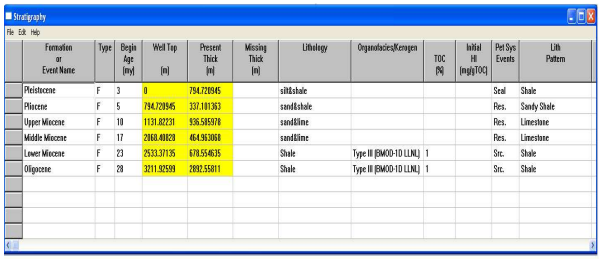
Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thick (m)	Missing Thick (m)	Lithology	Organofacies/Kerogen	TOC (%)	Initial HI (mg/gTOC)	Pet Sys Events	Lith Pattern
Pleistocene	F	3	0	1015.139		silt&shale				Seal	Shale
Pliocene	F	5	1015.139	558.8785		sand&shale				Res.	Sandy Shale
Upper&Middle Miocene	F	17	1574.01	800.1689		sand&lime				Res.	Limestone
Lower Miocene	F	23	2374.179	3268.498		Shale	Type III (BMOD-1D LLNL)	1		SR	Shale
Oligocene	F	28	5642.677	461.867		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale

Table 2: Well V-1 stratigraphy Table



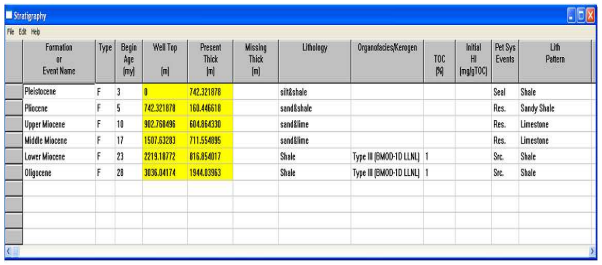
Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thick (m)	Missing Thick (m)	Lithology	Organofacies/Kerogen	TOC (%)	Initial HI (mg/gTOC)	Pet Sys Events	Lith Pattern
Pleistocene	F	3	0	1131.82231		silt&shale				Seal	Shale
Pliocene	F	5	1131.82231	1066.87221		sand&shale				Res.	Sandy Shale
Upper&Middle Miocene	F	17	2198.69452	1575.71075		sand&lime				Res.	Limestone
Lower Miocene	F	23	3764.40527	4866.69291		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale

Table 3: Well V-2 stratigraphy Table



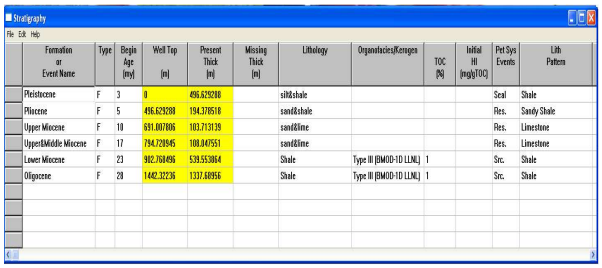
Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thick (m)	Missing Thick (m)	Lithology	Organofacies/Kerogen	TOC (%)	Initial HI (mg/gTOC)	Pet Sys Events	Lith Pattern
Pleistocene	F	3	0	794.728945		silt&shale				Seal	Shale
Pliocene	F	5	794.728945	337.101363		sand&shale				Res.	Sandy Shale
Upper Miocene	F	10	1131.82231	936.585978		sand&lime				Res.	Limestone
Middle Miocene	F	17	2068.40829	464.963068		sand&lime				Res.	Limestone
Lower Miocene	F	23	2533.37135	678.554635		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale
Oligocene	F	28	3211.92599	2892.55811		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale

Table 4: Well V-3 stratigraphy Table



Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thick (m)	Missing Thick (m)	Lithology	Organofacies/Kerogen	TOC (%)	Initial HI (mg/gTOC)	Pet Sys Events	Lith Pattern
Pleistocene	F	3	0	742.321878		silt&shale				Seal	Shale
Pliocene	F	5	742.321878	168.448618		sand&shale				Res.	Sandy Shale
Upper Miocene	F	10	902.768496	604.854330		sand&lime				Res.	Limestone
Middle Miocene	F	17	1507.62283	711.554095		sand&lime				Res.	Limestone
Lower Miocene	F	23	2219.18772	816.854017		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale
Oligocene	F	28	3036.04174	1944.83963		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale

Table 5: Well V-4 stratigraphy Table



Formation or Event Name	Type	Begin Age (my)	Well Top (m)	Present Thick (m)	Missing Thick (m)	Lithology	Organofacies/Kerogen	TOC (%)	Initial HI (mg/gTOC)	Pet Sys Events	Lith Pattern
Pleistocene	F	3	0	496.629288		silt&shale				Seal	Shale
Pliocene	F	5	496.629288	194.378518		sand&shale				Res.	Sandy Shale
Upper Miocene	F	10	691.007806	103.713139		sand&lime				Res.	Limestone
Upper&Middle Miocene	F	17	794.720945	108.047551		sand&lime				Res.	Limestone
Lower Miocene	F	23	902.768496	539.553864		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale
Oligocene	F	28	1442.32236	1337.58956		Shale	Type III (BMOD-1D LLNL)	1		Src.	Shale

Table 6: Well V-5 stratigraphy Table

Well V-1 Result & Discussions

Burial History Model

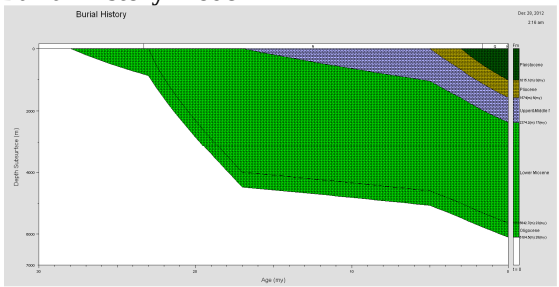


Fig 8: Well V-1 Burial History model

Two major source rocks; Oligocene and Lower Miocene shales are seen in this model. Oligocene was deposited and started forming around 28My whilst Lower Miocene commenced 23My.

Geothermal History Models

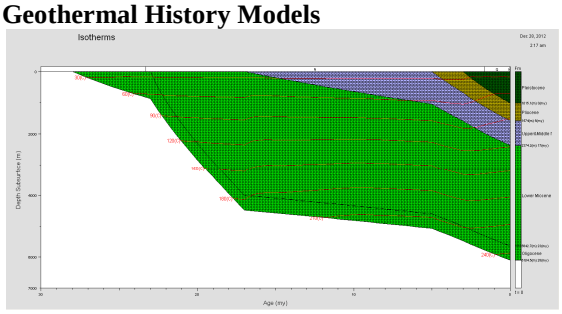


Fig 9: Well V-1 Isotherms model

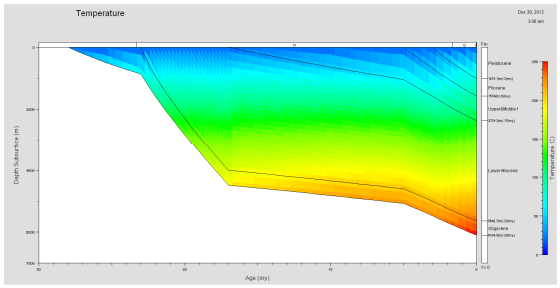


Fig 10: Well V-1 Temperature model

The lowest temperature of 30°C close to subsurface was recorded by both source units. The maximum value of temperature of 240°C for both units at depths 5642m and 6104m is also achieved. Average geothermal gradient is approximately 40°C/Km.

Maturity History Model

About half of entire Oligocene shales in this maturity window would turn to produce dry gas (2.6% to 5% Ro). The oil maturity window from early maturity to late maturity (0.5 to 1.3% Ro) began at 21My and ended at 18My. This window accounts for about 20% of hydrocarbons produced in this source rock. (1.3% to 2.6% Ro) phase in at some depths began at 18My and ended at 10My. Periods between 28My and 21My have under mature (0.04% to 0.5% Ro) Oligocene source rocks.

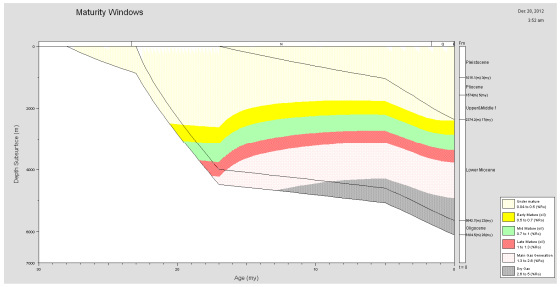


Fig 11: Well V-1 Maturity model

Oil maturity (0.5% to 1.3% Ro) in Lower Miocene shales extended from a wide period between 21My and present at various depths with a larger chunk of this source unit being under mature (0.04% to 0.5% Ro)

Well V-2 Result & Discussions

Burial History Model

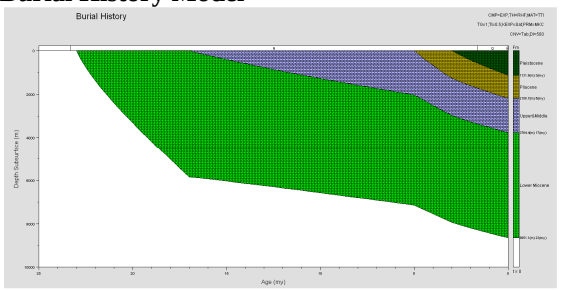


Fig 12: Well V-2 Burial history

Well V-2 is the second deepest well in this study penetrating to depths of 8651m. The main and only source unit in this well is a Lower Miocene formation with thickness of about 4886m.

Presently at about 7000m and below, temperatures recorded are 300°C which is substantial enough to facilitate early maturity of this source rock under ideal conditions as can be seen in figures 13 and 14

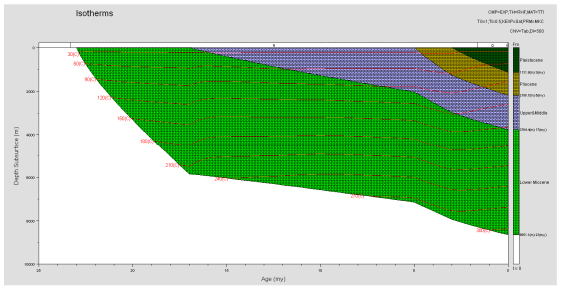


Fig 13: Isotherms for Well V-2

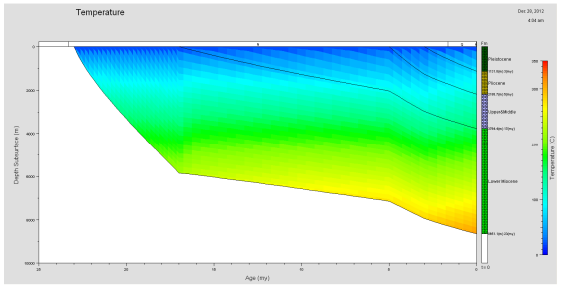


Fig 14: Well V-2 Temperature model

In this source rock, shales deposited below 2000m are mature to produce hydrocarbons (Oil and Gas). The Oil window (0.5% to 1.3% Ro) began about 21My. This includes early, middle and late maturity for shales of the Lower Miocene source rock.

Most areas within this unit lying above 2000m and close to surface are under mature (0.04% to 0.5% Ro). Main Gas generation (1.3% to 2.6% Ro) began 19My ago within source rock buried below 4000m.

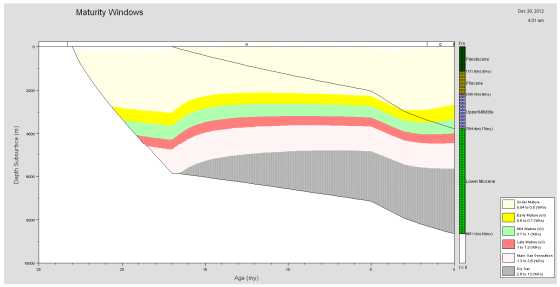


Fig 15: Well V-2 Maturity Windows model

Dry gas (2.6% to 13% Ro) which began forming about 16My ago accounts for a larger area of this source rock because a larger part of the source rock is buried at depths of very high temperatures and pressures.

Well V-3 Result & Discussions

Burial History Model

Shales of Oligocene and Lower Miocene formations form the two main source units within this well. Oligocene source rock is buried to a maximum depth of 6101m; presently 2892m thick. Lower Miocene is buried to a maximum depth of 3211m and is 678m thick presently. The begin formation of Lower Miocene coincides with subsidence in Oligocene source unit at about 3800m.

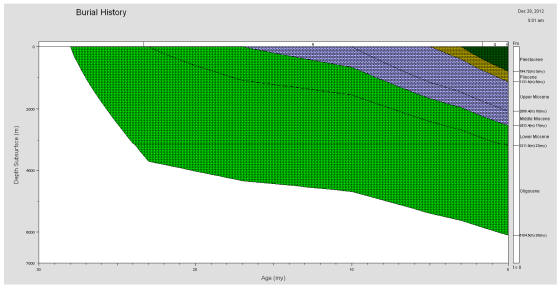


Fig 16: Well V-3 Burial history

Geothermal History Models

Within the two source units combined, temperatures ranging 30°C and 240°C are recorded from surface to depth maximum.

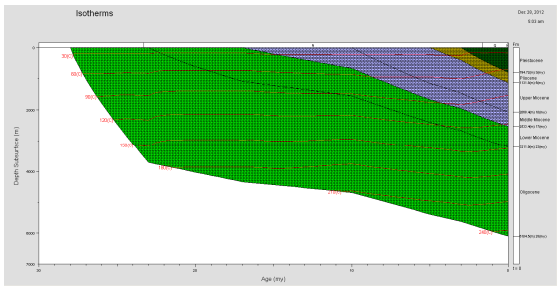


Fig 17: Isotherms model for Well V-3

Between 23My and about 3My, Lower Miocene shales experience very low degree of temperature; the highest value recorded slightly over 100°C.

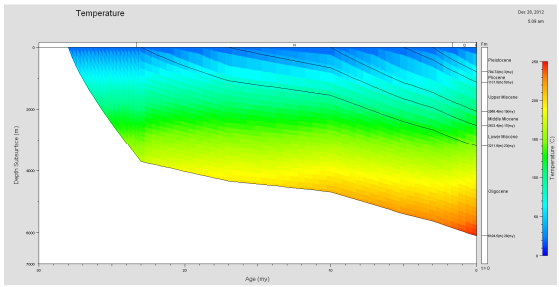


Fig 18: Well V-3 Temperature model

At present, temperature is about 150°C. Oligocene shales on the other hand are exposed to high degree of heat, especially at depths 3500m and below; temperature ranging 190°C and 250°C (19My to present). These areas of the Oligocene source unit experience very high geothermal temperatures and may mature earlier than Lower Miocene shales under ideal conditions. Average geothermal gradient is about 39C°/Km within this area.

Maturity History Model

For both source rocks as can be viewed in the above figure, areas lying and deposited above 2000m are under mature (0.04% to 0.5 Ro). This area accounts for about 40% of total maturity window. Between 2000m and 4000m lays the mature Oil windows (Early, Mid and Late Maturity); 0.5<Ro<1.3. These maturity windows (Early, Mid and Late) began at about 25My, 24My and 23My respectively.

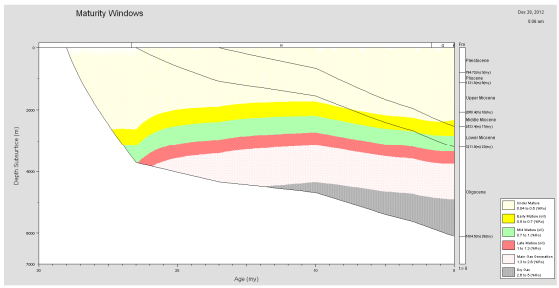


Fig 19: Well V-3 Maturity Windows

It is important to note that from figure 19, there is no late maturity of Oil for Lower Miocene source rock. The oil maturity windows in Lower Miocene are Early (0.5% to 0.7% Ro) and Middle Maturity (0.7% to 1% Ro). No Gas window also exists for the Lower Miocene source unit. Main Gas generation window (1.3% to 2.6% Ro) began about 22.5My in Oligocene source rock between about 3200m and 4400m.Below 4400m lays the Dry Gas generation phase (2.6% to 5% Ro) which began about 14My ago.

Well V-4 Result & Discussions

Burial History Model

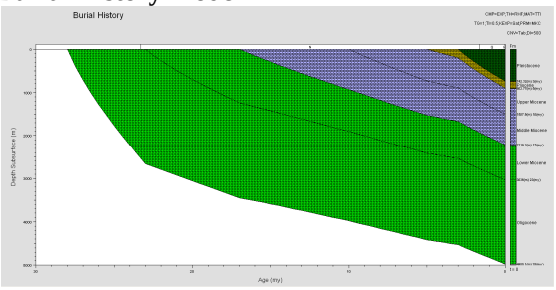


Fig 20: Well V-4 Burial history

Two active source rocks occur in this petroleum system namely Oligocene and Lower Miocene deposited 28My and 23My ago respectively; Oligocene being the main source unit in this model. Shale is the dominant lithology for both source units. Oligocene formation is very thick and buried to depths about 4980m. Present thickness remains 1944m and 816m for Oligocene and Lower Miocene formations respectively.

Geothermal History Models

Since this model shows same or equal temperature values at certain depths, both source units generated the same temperature at particular depths. At a depth of about 200m, 30°C temperature is recorded for both Oligocene and Lower Miocene formations.

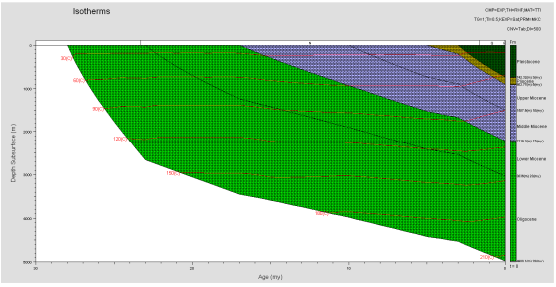


Fig 21: Isotherms model for Well V-4

There are variations in temperatures as depth increases as would be viewed in a subsequent model in figures 21. An average value of 120°C is recorded for approximately every 2.4Km change in depth; makes the geothermal gradient of this well location area about 42°C/km.

At depths below 2000m (25My to present), Oligocene source rock temperatures range over 100°C to slightly above 210°C. From 28My to 25My, temperatures recorded remained below 100°C as can be seen in figure 22. Presently, high temperatures, approximately 210C are recorded at depths below 4500m. Lower Miocene source rock buried above 2000m between 23My and about 5My experienced temperatures below 100C; the remainder recorded values not exceeding 150C at depths below 2000m (3My to present).

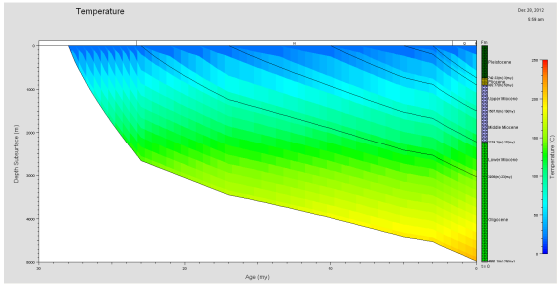


Fig 22: Well V-4 Temperature model

Maturity History Model

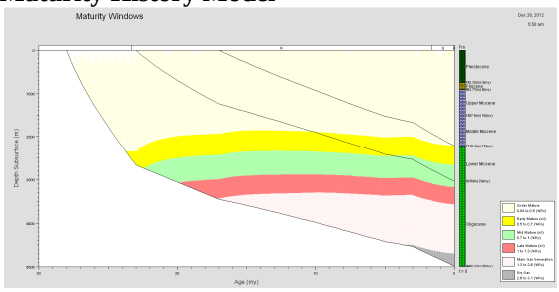


Fig 23: Well V-4 Maturity Windows

For most areas of both source rocks buried and lying above 2000m, the shales are under mature (0.04% to 0.5% Ro). Vitrinite reflectance (Ro) values for Oligocene source rock between 0.5% and 1.3% indicate that the source unit lies within maturity zone. From figure 23, early maturity (0.5% to 0.7% Ro), mid maturity (0.7% to 1% Ro) and late maturity (1% to 1.3% Ro) began about 24My, 22.3My and 20My ago respectively. Main Gas generation (1.3% to 2.6% Ro) zone lies beneath 3000m. Dry Gas (2.6% to 3.1% Ro) began generation about 3My ago and accounts for a small percentage of total matured hydrocarbons. Lower Miocene source unit maturity windows only fall within the under mature, early mature and mid mature zones. No Main gas or Dry Gas generations for Lower Miocene.

Well V-5 Result & Discussions

Burial History Model

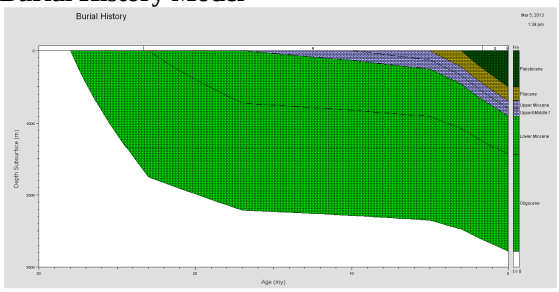


Fig 24: Well V-5 Burial history

Two major source units, Oligocene and Lower Miocene can be viewed in figure 24. Oligocene which began forming 28My is buried to a maximum depth of about 2780m and is about 1337m thick presently. Lower Miocene source rock began forming at 23My; maximum depth is about 1442m and has a present thickness of about 539m. This well is the shallowest well in this study. Dominant lithology for both units is shale.

Geothermal History Models

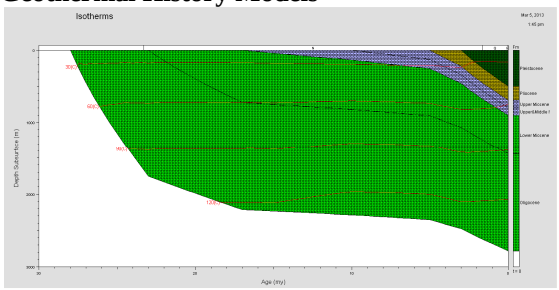


Fig 25: Isotherms model for Well V-5

Temperature values as seen in figures 25 and 26 show relatively low temperatures recorded over the period between the formation of the source rocks and present as far as this study is concerned. For both units between their periods of deposition till present, temperature values recorded from surface to about 1000m are under 100°C. Oligocene source rocks show substantive thermal activity below 2000m especially between 25My and present (0My) with temperatures between 100 and 140°C. Lower Miocene source rocks show little thermal activity in terms of temperature.

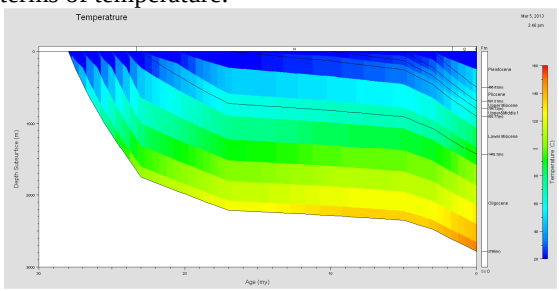


Fig 26: Well V-5 Temperature model

Maturity History Model

Most parts of both Oligocene buried and lying above 1300m are under mature (0.04% to 0.5% Ro).

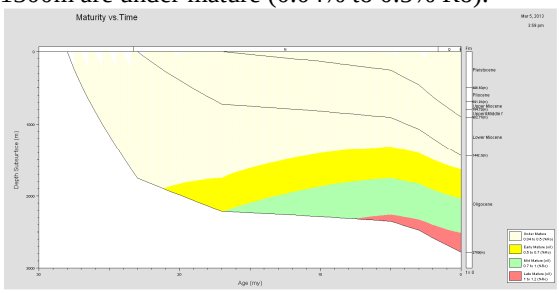


Fig 27: Well V-5 Maturity Windows

Early Oil maturity (0.5% to 0.7% Ro) began at 21.5My with its peak occurring at 5My about 1400m deep. Middle Oil maturity (0.7% to 1% Ro) began at 16.5My. Shale deposited and buried around 2000m has vitrinite reflectance values of a mid-mature source unit. Late Maturity (1% to 1.2% Ro) began around 7My and at depths below 2000m. Lower Miocene source rock is not mature to produce hydrocarbons. No Gas and Dry gas maturity windows occur for this well as can be seen in figures 27.

Summary and Conclusion

Based on the maturity of source units, a summary of one Dimensional (1D) Oil and Gas Generated/Expelled is undertaken for all six wells as per modelling results; V-1, V-2, V-3, V-4 and V-5.

Present Day Oil Generated

mg/g TOC	S-1	V-1	V-2	V-3	V-4	V-5
Lower Miocene	43	-	48+18 / 2	17	15	-
Oligocene	50	48	-	43	42	23

Table 7: Present Day Oil Generated for all Wells

Present Day Gas Generated

mg/g TOC	S-1	V-1	V-2	V-3	V-4	V-5
Lower Miocene	130	1	40+135 / 2	35	25	-
Oligocene	132	120+125 / 2	-	126	116	49

Table 8: Present Day Gas Generated for all Wells

Present Day Oil Expelled

mg/g TOC	S-1	V-1	V-2	V-3	V-4	V-5
Lower Miocene	-	-	-	-	-	-
Oligocene	-	-	-	-	-	-

Table 9: Present Day Oil Expelled for all Wells

Present Day Gas Expelled

mg/g TOC	S-1	V-1	V-2	V-3	V-4	V-5
Lower Miocene	76	2	108	-	-	-
Oligocene	90	43	-	33	-	-

Table 10: Present Day Oil Expelled for all Wells

As per table 7, the highest quantities of Oil Generated from Oligocene/Lower Miocene source units presently is within Well S-1 (Eastern Moattama Basin); 50mg/g TOC, with the exception of Well V-2, which averages 33mg/g TOC in quantity for Lower Miocene present Generation, Oligocene still generates much Oil presently than Lower Miocene source unit for all the other Wells.

Oligocene formation in Well S-1 generates much quantity of Gas at present, 2mg/g TOC more than its Lower Miocene counterpart. Oligocene formation in Wells V-1, V-3 and V-4 also produce substantial amounts of Oil with Well V-5 located on the Western region of Mergui Basin, generating the least Oil quantity.

Presently, there is no Oil expelled from all source units into traps of reservoirs of all the six Wells considered in this study as per table 9. Migration of Oil from source rocks into the reservoirs could be impeded by capillary pressure or forces which cannot be overcome by the buoyant forces within these source units.

Well V-2 Lower Miocene formation (North-east Moattama Basin) which remains the main and only source unit presently records the highest expulsion of 108mg/g TOC followed by Well S-1 source units.

Based on the kitchen areas outlined, further wells could be drilled to exploit the prospective hydrocarbons bearing areas within the Central Andaman Sea Back arc depression.

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