LOG MOTIF AND RESERVOIR PROPERTIES IN THE CENTRAL MALAY BASIN

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Technology (Hons)
(Petroleum Geoscience)

MAY 2014

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Geoscience Programme
Universiti Teknologi PETRONAS
in a partial fulfillment of the requirement for the
BACHELOR OF TECHNOLOGY (Hons)
(PETROLEUM GEOSCIENCE)

Approved by,

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TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NOR AQILAH BINTI MOHD ANUAR

ABSTRACT

The Malay basin is a Tertiary rift basin located in between Peninsular Malaysia and Vietnam offshore. A review on lithology, pressure, temperature and heat flow of the basin is conducted at two exploration wells; Tujoh-1 and Tangga-1. This study is carried out to investigate depositional environment and factors that controls overpressure in the basin. Using log motif and thermophysical properties interpretations, the reservoir quality and the main mechanism of overpressure will be discussed.

Tidal bar and mouth bar are developed within distributary channels, along delta fronts and in the outer parts of estuaries. These facies have good reservoir qualities due to high lateral and vertical homogeneity of its morphology and grain size distribution. Previous works have revealed that the basin has high average heat flow (85 mWm^{-2} and 125 mWm^{-2}) and geothermal gradient (45 $°Ckm^{-1}$ and 60 $°Ckm^{-1}$). A study on the subsurface pressure revealed that the top of overpressure occurs between 1800m to 2000m depth. The overpressure is confined in Group E for Tujoh-1 well and Group F for Tangga-1 well. The main cause for overpressure in the basin is believed due to disequilibrium compaction.

ACKNOWLEDGEMENT

First and foremost, *Alhamdulilah*, all praises to Allah for the strengths and His Blessing upon completing the Final Year Project (FYP). I would like to express my gratitude to my supervisor, Associate Professor Wan Ismail Wan Yusoff for his guidance, support and technical opinions. He has motivated me to explore the thermophysical properties and I have learnt a lot from his priceless experience and knowledge.

Also, I would like to dedicate my deepest appreciation to Universiti Teknologi PETRONAS, especially Geoscience and Petroleum Engineering lecturers, colleagues and technicians for their endless moral support, suggestions and encouragement to complete this project. Commitments, assistances and friendships from all parties have meant a lot for me to develop my career as GEOSCIENTIST in future.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION TO THE STUDY

1.1 Location and Background of the Study

The study area is located in the Malay basin, between Peninsular Malaysia and Vietnam offshore. The basin is a part of continental core known as Sundaland core which has 500 kilometres length, 250 kilometres width and 14 kilometres sediment filled up (Petronas, 1999). The basin is ranked among prolific petroleum producing in the Southeast (SE) Asia with excellent kitchen and rich source rocks (SEG, 2010).

Various studies have been conducted by oil operators to understand stratigraphy, sediment history, structural configuration and palaeoenvironment of the Malay Basin. However, the overpressure development in the basin is not discussed in details. It is estimated that more than 80% of wells drilled during the earlier phase were terminated because of overpressure (Mohd Shariff Kader, 1994). This study will discuss on depositional environment of the Malay basin at two exploration wells and focus on the overpressure development based on pressure and temperature profiling analysis.

1.2 Problem Statement

Several methods have been proposed to predict the pore pressure in the overpressure region. However, there are still lack of understanding on the factors that control overpressure and how overpressure has evolved through time. This can cause difficulty for operators who want to explore in greater depth since there is insufficient studies in the pore pressure profiling and its relationship to the reservoir quality. The profiling is important for operators to predict the hydrocarbon accumulation in the study area.

1.3 Objectives

The study attempts to achieve three objectives:

1. To study the log motif in relation to the environment of deposition
2. To investigate the relationship of thermophysical properties to pore pressure. This includes temperature gradient, thermal conductivity and heat flow.
3. To examine factors that control overpressure and relate it to the reservoir quality

1.4 Scope of the Study

The study integrates analysis of log motif and thermophysical properties of rock. Correlation will be carried out at two exploration wells in different fields in order to generate the depositional correlation and determine the facies succession.

The thermophysical properties are the effects of the heat transport across the earth crust which influences the pore pressure properties. This includes the lithology, porosity and temperature interpreted from well logging data. From that, the overpressure distribution will be examined and related it to hydrocarbon accumulation. The computed profiles in the Malay basin will be compared to profiles acquired in the nearby onshore area which is Kelantan Delta.

1.5 Relevancy of the Study

The need for oil operators to understand the reservoir architecture at greater depth is crucial, as the current exploration activities are focused on older sediments and fractured basement. Since the exploration trends are changing, the necessity to study about the pore pressure and thermal properties of the rocks are important. Hence, this study can provide some technical opinions in exploring the hydrocarbon reservoirs in the study area.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW AND THEORY OF THE STUDY

2.1 Geological Setting

The basin is a northwest-trending Tertiary basin, formed during the late Oligocene, about 35Ma ago, and is filled by Miocene sediment and now with shallow-marine siliciclastic sediments (Mazlan, 2007).

Tapponier et al. (1982) suggested that the basin have formed due to collision of India and Eurasia continents which caused major wrench faults to the South and East. Due to collision, the mainland of Asia has extruded to south-eastward and the sinistral strike-slip fault has reactivated (see FIGURE 29). On the other hand, another model by Hutchinson (1989) suggested that crustal uplift and extension happened due to thermal doming of central Sundaland during Late Cretaceous.

Daly et al. (1991) developed a more comprehensive model to describe the formation of the Malay basin and has the same concept with previous model proposed by Hutchinson (1986). This model is based on the reconstructed tectonic plate of the region whereby the SE Asia mainland was rotated clockwise due to contraction of mainland Asia rather than large scale Eastward extrusion (Wan Ismail, 1993). However, a widely used model for Malay basin is the hypothesis of extrusion by Tappnnier (1982).

2.2 Structures

The structures in the Malay basin have been described based on the trap styles. The main structural pattern is compressional anticlinal which the pattern is different in the complexity based on simple domes structure, domes associated with faults and basement related structure. It can be observed that the faults are trending in E-W and NW-SE directions at the SE part while in the N-S direction at the NW part (see FIGURE 30).

2.3 Stratigraphy

There are four known stratigraphy nomenclatures in the Malay basin; Seismic Group by Esso (late 1960s), Formation by Armitage and Viotti (1977), Formation by Conoco (1979, 1985) and Tertiary Unit by Carigali (1988). These nomenclatures were established from previous oil and gas companies developed at their respective exploration area. This study will refer to nomenclature by Esso since it is widely used in the published researches.

The stratigraphy nomenclature by Esso was based on seismic stratigraphy which comprises eleven seismic groups (see FIGURE 31). The groups start from the youngest (A) to the oldest (M). These groups represent the major sequence boundaries and are erosional unconformities on the basin flanks (Petronas, 1999). The basin is made up almost by clastic sedimentary rocks. The lithology consists of a thinly layered sand-shale deposition known as layer-cake configuration. However, there is some intermittent calcareous sandstone prevails in some section (Wan Ismail, 1993). Coal can be found in groups D to H; EPIC (1994) described coal is primarily in group E however coal in group I of coastal-plain setting is the most prominently (SEG, 2010).

2.4 Tectonic Framework and Sediment History

The sedimentation history of the Malay basin started with syn-rift deposition of oldest groups M, L and K that infilled the half grabens until Early Miocene (Ngah, 1990). These groups are from continental and coastal plain with some occurrence of lacustrine. This deposition has caused subsidence to the half grabens and created extensional fault during Late Oligocene.

The continuous thermal subsidence has resulted to the deposition of groups L to D which has increasing influence of marine sediment. At this time, the compressional event also took place that resulted to the local basin inversion. These structures are believed to happen correspond to the readjustment of the fault blocks.

During H times, it is observed that at the SE part, the basin was eroded due to uplift process. This has created three erosional unconformities (L sandstone, K sandstone and J sandstone) due to erosion of sediment in groups D, E, F, H and I. While at the NW part, there is no evident of erosion and the unconformity is marked by insignificant disconformity surfaces. The upper groups A and B consists mainly claystone with lignite, sandstone and dolomite interbeddings (see FIGURE 32).

2.5 Log Motif

The shape of gamma ray (GR) logs is useful to interpret the depositional environments. This is because the log is found to be variable, has greater detail and shows the sediment character. Abrupt changes in GR logs response are commonly related to the sharp lithological breaks associated with unconformities and sequence boundaries (Krassay, 1998).

GR log is a good indicator to represent sand-shale content as it measures the natural radioactivity of rocks. There are five log trends (see FIGURE 33); bell shape, funnel shape, cylindrical shape, bow shape and irregular shape. These shapes can be interpreted in terms of grain size trends and represent cycles in the sedimentological association. Large grain size will indicate low gamma ray (sand) and small grain size will show high gamma ray (shale). The sedimentological implication of this relationship leads to direct correlation between facies and log shape (Omoboriowo, Chiadikobi & Chiaghanam, 2012).

2.6 Thermophysical Properties

Thermal conductivity is defined as heat flow per unit temperature gradient. It is a transport property respect to lithology, anisotropy, pressure and temperature. For a reservoir, the thermal conductivity is the total thermal conductivity of the rock and the filled liquid. The thermal conductivity can be assumed as rock properties based on two factors; the mineral thermal conductivity is higher than fluid thermal conductivity and the mass fraction of mineral is higher than fluid fraction (porosity) per bulk volume.

Several studies have been conducted to study the effects of pressure on thermal conductivity. From the early studies, it is observed that thermal conductivity increases respect to the pressure. In this case, the applied pressure is the net confining pressure or the net overburden pressure in the reservoir.

Ilmutdin et al. (2006) have done a comprehensive study on the effect of pressure and temperature on the thermal conductivity of the rocks. From the study, it is observed that the profiling between thermal conductivity and pressure (see FIGURE 34) and thermal conductivity and temperature (see FIGURE 35) are non-linear regardless the rock types. However, the effect of pressure is smaller compared to the effect of temperature. This may be caused by the rock nature, mineralogical composition, porosity and density.

CHAPTER 3

METHODOLOGY

3. RESEARCH METHODOLOGIES

Different methods have been adopted to evaluate the log motif and reservoir properties in the central Malay basin. This research is based on empirical methodology where interpretations are taken from real well data. This approach is the most reliable to reduce uncertainties and represent the conditions of the wells.

For this study, the research materials were provided by Petronas, Malaysia. The study will be carried out by using Microsoft Office Excel, Petrel and PetroMOD by Schlumberger. Two selected wells will be used for this study named as Well T1 and Well T2. The primary source of data is taken from well logging data. Data includes:

TABLE 1: Data Availability

T1 Well	**T2 Well**
• Gamma Ray (GR) log • Neutron Porosity ($\emptyset_N$) log • Density Porosity ($\emptyset_D$) log • Sonic Velocity Data • Temperature Data • Pressure Data	• Gamma Ray (GR) log • Neutron Porosity ($\emptyset_N$) log • Density Porosity ($\emptyset_D$) log • Temperature Data • Pressure Data

3.1 Project Activities

A workflow is designed to achieve the objectives. In general, the workflow can be divided into three sections; fieldwork, log motif analysis and reservoir properties analysis. The steps are:

1) The data is prepared and quality checked. This involves collecting the field data and checking appropriate parameters for the analysis.
2) The data is analysed and interpreted. This step focuses on two outputs as shown:
   i. Correlation is done at the older sediments. The GR log shapes will be studied to predict the possible environment of deposition (EOD).
   ii. For reservoir properties analysis, various parameters are cross-plotted to examine the trend and relationship towards pore pressure distribution. From that, the overpressure distribution is discussed.
3) The computed cross-plots from the Malay basin will be compared to the nearby onshore data, Kelantan Delta.

3.2 Log Motif Analysis

Figure 1 shows the data preparation for log motif analysis. In this analysis, the fields are correlated based on the chronostratigraphic correlation. This means that the structural and stratigraphic units are determined based on fossil assemblages. After correlation is done, the gamma shapes are studied at higher-resolution to determine the environment of particular reservoir.

FIGURE 1: Data preparation for Log Motif Analysis

3.3 Reservoir Properties Analysis

Figure 2 shows the workflow for reservoir properties analysis. In general, three main inputs from the logging data are used to derive appropriate parameters. Microsoft Excel is used to calculate specific outputs and do graphs plotting.

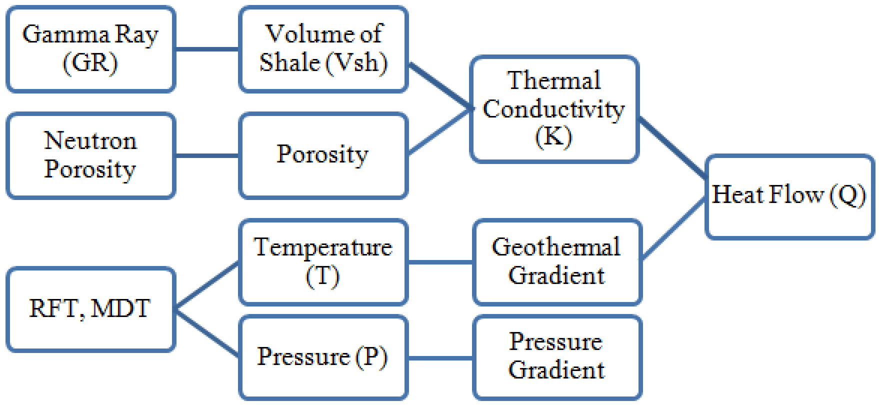


FIGURE 2: Data preparation for Reservoir Properties Analysis

3.3.1 Pressure Gradient and Temperature Gradient Calculation

Pressure and temperature gradient are calculated as a function of vertical depth. Pressure gradient is expressed in psi/m and temperature gradient as °C/m which are equivalent to standard acceptance.

$$\boxed{Pressure\ Gradient = \frac{Pressure}{Vertical\ Depth\ x\ 0.052}}$$

$$\boxed{Temperature\ gradient = \frac{Temperature}{Vertical\ Depth}}$$

3.3.2 Thermal Conductivity and Heat Flow Calculation

Thermal conductivity is calculated by using empirical equations (1993). The equations use data from log response, which depends on V_{shale} and neutron-porosity distributions. In this equation, X, Y and Z are constant based on thermal facies defined from previous study.

The standard unit for thermal conductivity is W/m°K. In contrast, heat flow is calculated from thermal conductivity and temperature gradient. The standard unit is W/m^2.

$$\boxed{Thermal\ Conductivity\ (k) = X(Y)^{V_{Sh}}(Z)^{\emptyset_n}}$$

$$\boxed{Heat\ Flow\ (Q) = k\ x\ Temperature\ Gradient}$$

TABLE 2: Empirical Equations (Wan Ismail, 1993)

kf	Limit of Log Parameters	Empirical Equation
kf1	Vf < 20%, Øn < 36%	$k_{emp} = 6.86\ (0.99)^{Vf}(0.98)^{Øn}$
kf2	Vf = or > 20% and < 40%, Øn < 35%	$k_{emp} = 6.43\ (0.99)^{Vf}(0.98)^{Øn}$
kf3	Vf ≥ 40% and < 60%, Øn> 18% < 35%	$k_{emp} = 10.59\ (1.00)^{Vf}(0.96)^{Øn}$
kf4	Vf ≥ 60%< 85%, Øn>18% < 39%	$k_{emp} = 5.83\ (0.99)^{Vf}(1.00)^{Øn}$
kf5	Vf >13%< 30% Øn = or > 33%<60%	$k_{emp} = 13.14\ (1.09)^{Vf}(0.91)^{Øn}$
kf6	Vf ≥ 30% and < 40%, Øn ≥ 35%<49%	$k_{emp} = 12.95(1.03)^{Vf}(0.98)^{Øn}$
kf7	Vf = or ≥ 40%<85%, Øn = or ≥ 35%<61%	$k_{emp} = 15.24\ (1.01)^{Vf}(0.94)^{Øn}$

3.4 Gantt Chart

The gantt charts for Final Year Project I and Final Year Project II are attached in Appendix section (see TABLE 5 and TABLE 6).

CHAPTER 4

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

In this study, two wells which are located in the central Malay basin are used for log motif and reservoir properties analysis. These wells are T1 and T2 from gas productions (see FIGURE 3 and FIGURE 4). Data shows that T1 well was drilled up to 2168.96m while 1846.17m for T2 well. It is assumed that the wells could not be drilled at deeper section as it reached the overpressure zone.

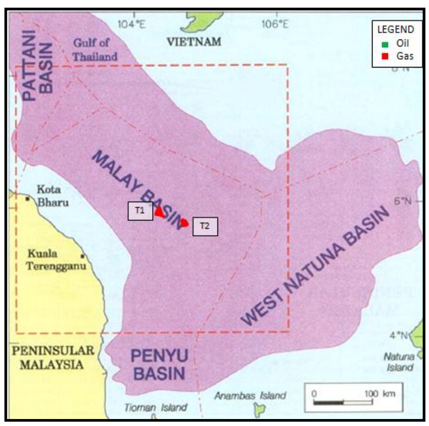


FIGURE 3: Location of the study area (The boxes indicate T1 well and T2 well)

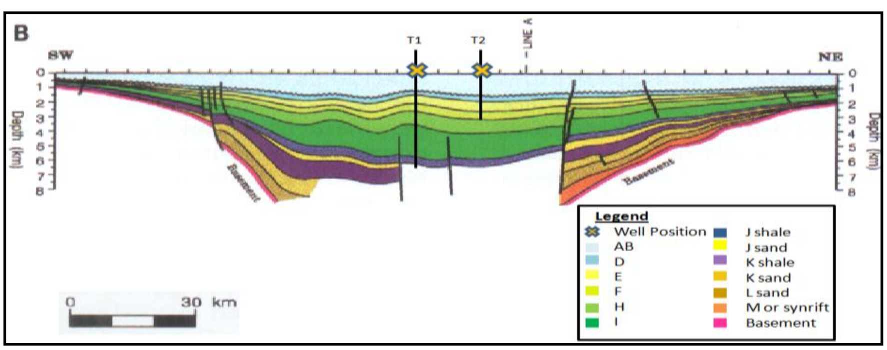


FIGURE 4: Cross-section of the study location (modified after ESSO, 1985)

4.1 Environment of Deposition Interpretation

The wells are not correlated due to absence of coal and significant flooding surfaces between both wells. However, the framework of the study is based on chronostratigraphy chart developed by ESSO in 1982 named as Well Penetration Chart of Sedimentary Groups (see TABLE 3). Chronostratigraphy correlation correlates the rocks based on paleontological intervals of time defined by recognized fossil assemblages (see FIGURE 5). It is crucial for accurate paleogeographic reconstructions as it places the rock in time and sequence positions.

TABLE 3: Well Penetration Chart of Sedimentary Group (ESSO, 1982)

Group	**Depth for Tujuh-1 Well (ft)**	**Depth for Tangga-1 Well (ft)**
A	195’	215’
B	?	?
D	4369’	3023’
E	5934’	4293’
F	7026’	5783’
Total Depth	7116’	6057’

This analysis focuses on groups D and E. The upper groups which is Group A and Group B may have similarities in the log characteristics with older groups, but the groups have high amount of silt and shale. In general, these groups are classified as non-reservoir prone which is not the interest zones.

Group D has a regional unconformity at the top of the group. The main lithology comprises very fine to fine grain; which indicates silt to shale deposits. A number of fining upward packages are present in both wells. These packages begin with sharp base or scoured. The group contains no coals at both wells. This indicates that the rate of sedimentation is increased during this time. The group has progressed towards marine-influence depositional environment where saline water kills the coal forming plant which explains the absence of coal.

The main lithology for Group E is sand deposits in Tujoh-1 well and interbedded sand-shale in Tangga-1 well. Some occurrence of coal can be observed in Tujoh-1 well which indicates the area has lacustrine and tidal-influenced depositional environments. The coal in group E is the most abundant compared to other groups as it is probably a function both of the wide fresh water swamp area and the fact that lowstands may be lacustrine dominated (EPIC, 1994). The possible environments for both groups are tidal channel, lower coastal plain and deltaic deposits (which have lacustrine and tide-influenced delta).

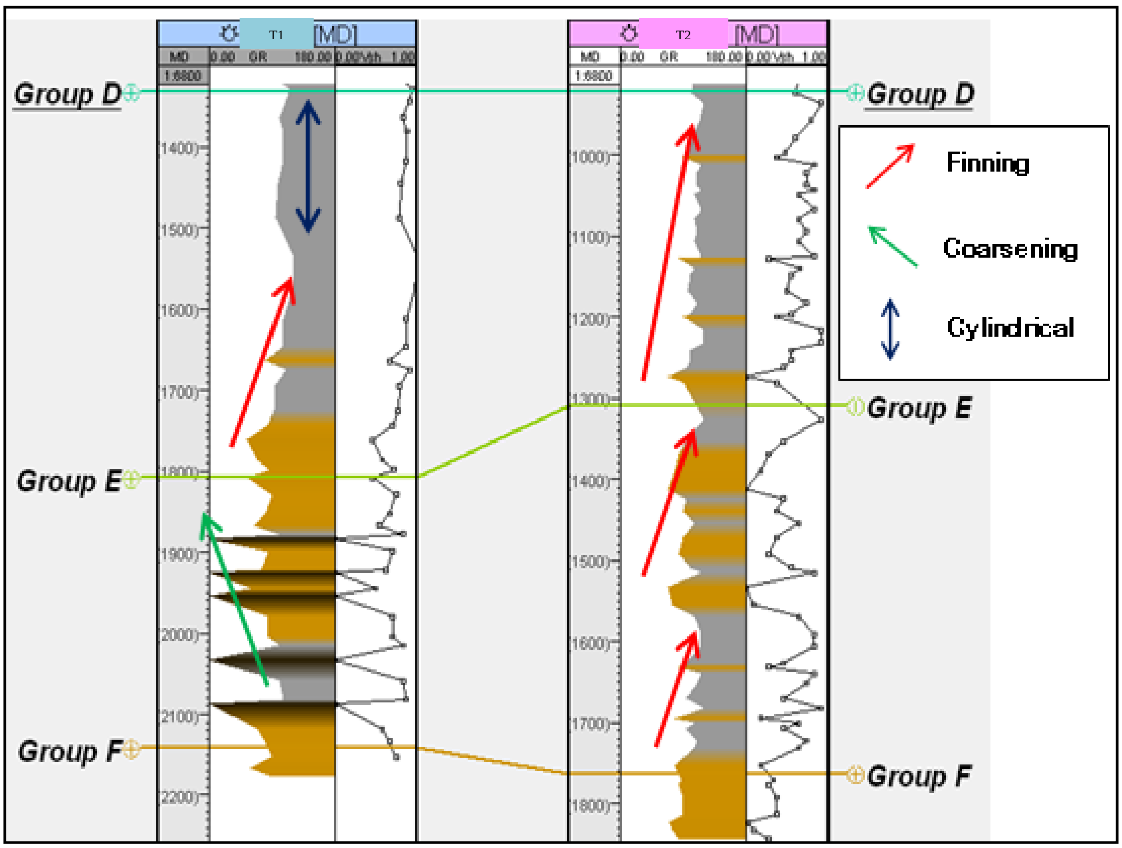


FIGURE 5: Chronostratigraphy correlation of T1 well and T2 well

Tidal/Mouth Bar Facies

Below is well log section from Tujoh-1 well. The gradual base coarsening upward trend from gamma ray log is consistent to tidal bar facies succession.

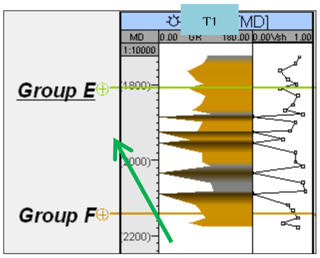


FIGURE 6: Funnel shape can be observed in well log section of T1 well

Tidal Channel

Below is well log section from Tujoh-1 well. Channel sand usually has a sharp base and cylindrical pattern of gamma ray, which is consistent with the gamma ray log over here.

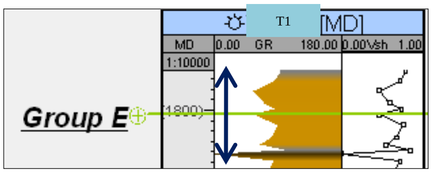


FIGURE 7: Cylindrical shape can be observed in well log section of T1 well

Tidal Point Bar

Below is well log section from Tangga-1 well. The gamma ray log here is corresponding to tidal point bar at marine transgression which has sharp base and fining upward pattern.

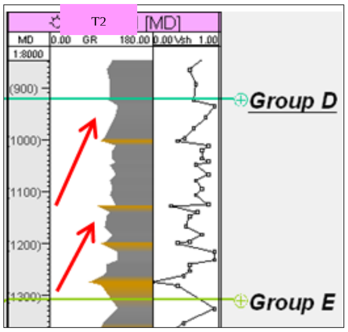


FIGURE 8: Bell shape can be observed in well log section of T2 well

4.1.1 Analogue Model

The Mahakam Delta is known as one of the significant tide-influenced deltas (see FIGURE 9). It has been subjected to many studies especially on the interaction between fluvial and tidal process, and channel abandonment. This model can be related to the Malay basin depositional environment. Previous sedimentology and stratigraphy studies have proved that the Malay basin environment develops from lacustrine-influence environment to fluvial and the present day towards marine-influence depositional system.

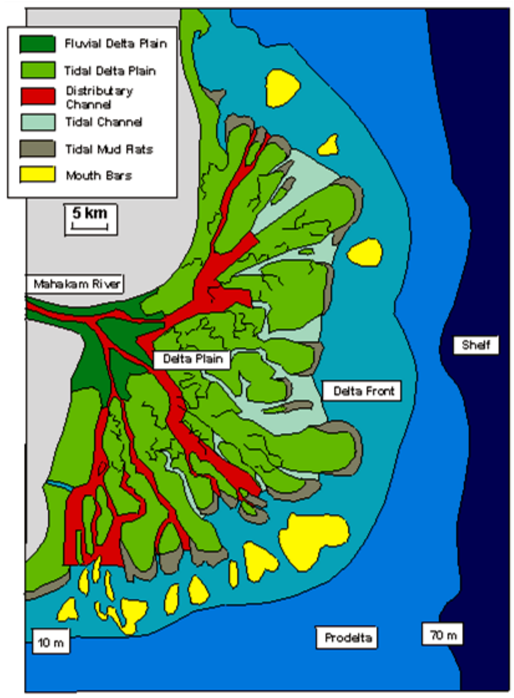


FIGURE 9: Analogue model of the Mahakam Delta, Indonesia

4.1.2 Reservoir Quality Interpretation

In terms of reservoir quality, T1 well is better compared to T2 well. This is because T1 well composes of high sand content which is able to store more fluids inside the pore space. As interpreted earlier, the facies are tidal bar and mouth bar which are developed within distributary channels, along delta fronts and in the outer parts of estuaries. These facies have moderate to good properties to become reservoir due to high lateral and vertical homogeneity of its morphology and grain size distribution.

4.2 Reservoir Properties Interpretation

4.2.1 Relationship between Pressure and Depth

Depth is plotted against pressure. In this attempt, pressure increases with the depth (see FIGURE 10 and FIGURE 11). However, at some point, the increment is not linear to the hydrostatic line. This change indicates top of overpressure which develops in the wells. The top of overpressure is confined in Group E for T1 well and Group F for T2 well.

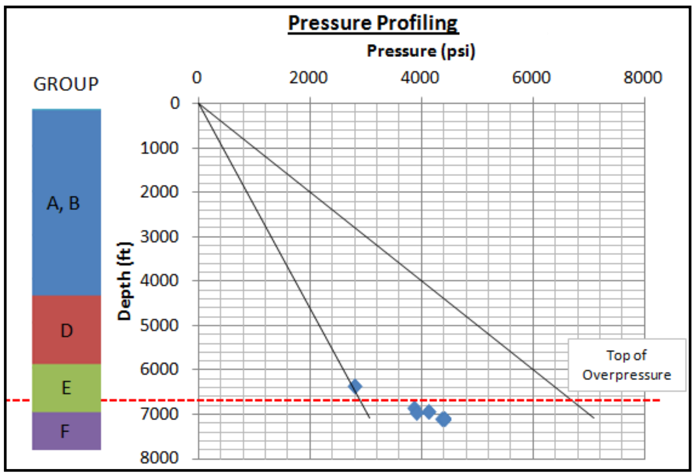


FIGURE 10: Pressure profile at T1 Well (The dotted red line indicates the overpressure zone in this well which confines in Group E)

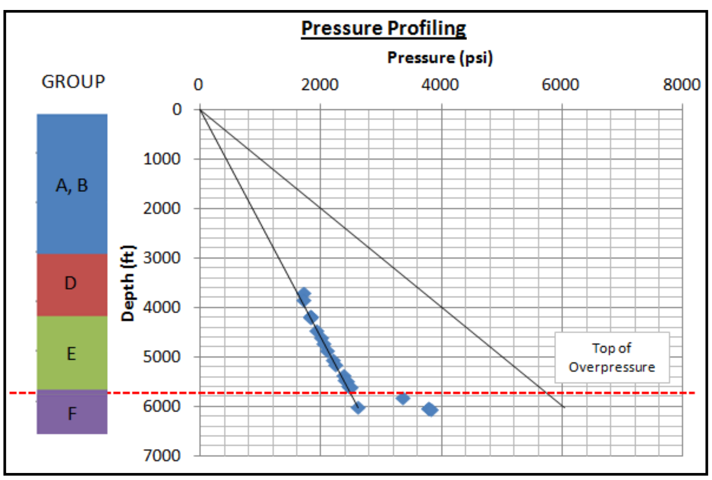


FIGURE 11: Pressure profile at T2 Well (The dotted red line indicates the overpressure zone in this well which confines in top of Group F)

4.2.2 Relationship between Temperature and Depth

Depth is plotted against temperature. A linear trendline is observed with increment of the depth (see FIGURE 12 and FIGURE 13). Using exponential trendline, slightly concave downward shapes can be observed at both wells. These shapes indicate that there is a prominent upward component of fluid inside the wells. However, the inference could not be confirmed unless more temperature data at deeper part is provided.

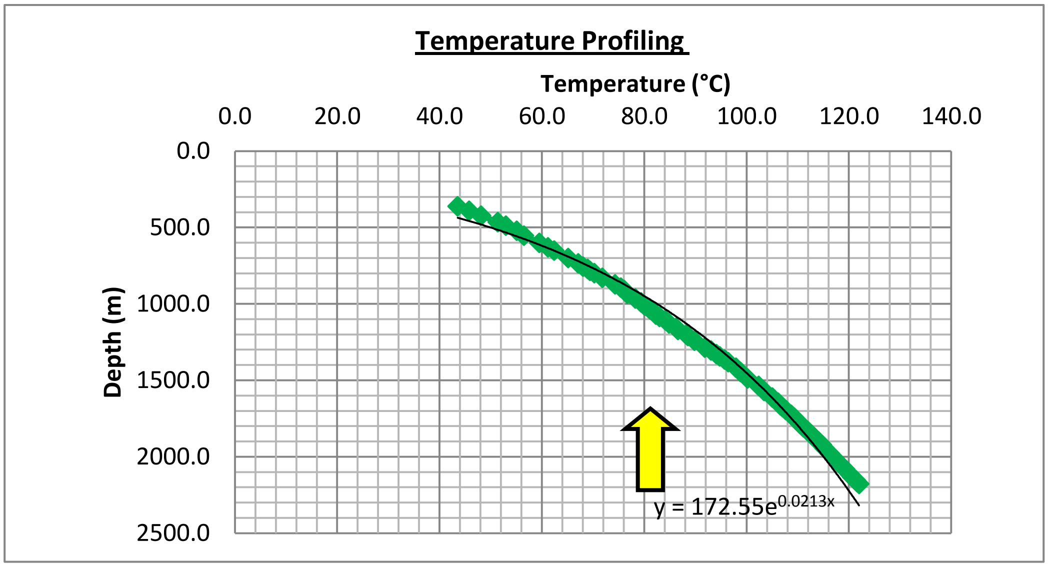


FIGURE 12: Temperature profile at T1 Well

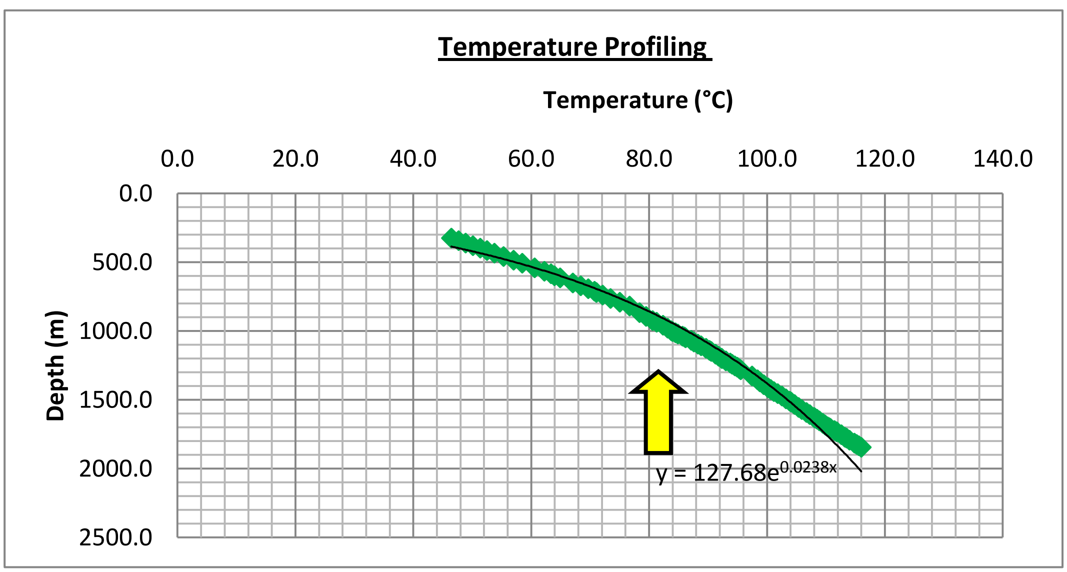


FIGURE 13: Temperature profile at T2 Well

4.2.3 Relationship between Thermal Conductivity and Volume of Shale

Depth is correlated to thermal conductivity (K) and volume of shale (Vshale). In this attempt, no significant trends are observed at thermal conductivity and volume of shale distribution with increasing depth (see FIGURE 14 and FIGURE 15). When both profiles are compared, it is noticed that high amount of shale gives low value of thermal conductivity and vice versa.

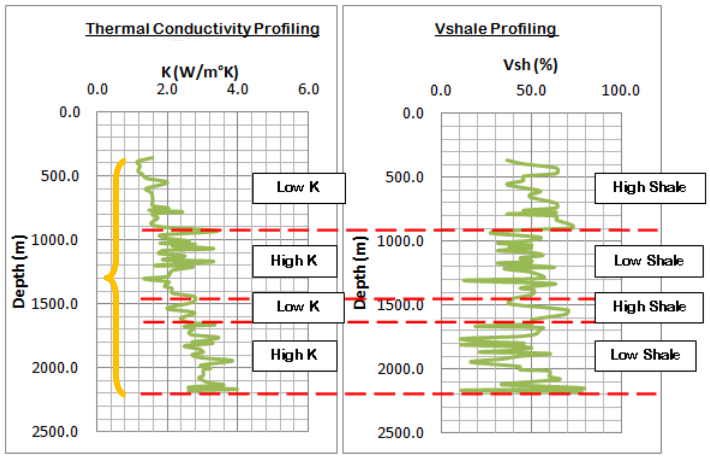


FIGURE 14: Thermal conductivity and volume of shale profiling at T1 well (It can be observed that T1 well has an increasing trend of thermal conductivity as it goes deeper. This is due to high amount of sand content which gives the increasing trend)

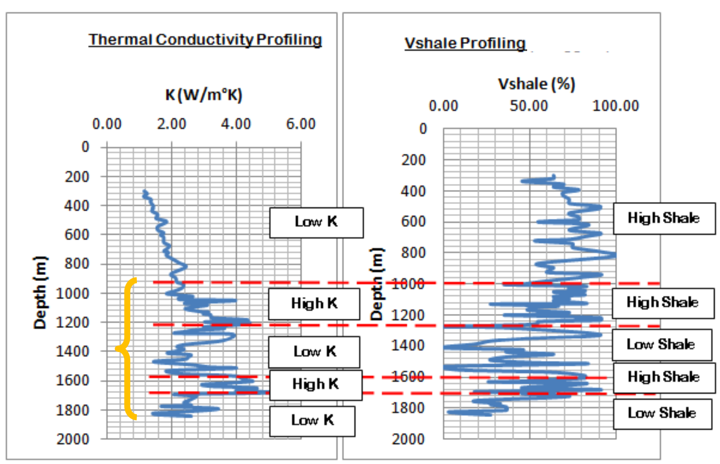


FIGURE 15: Thermal conductivity and volume of shale profiles at T2 well (It can be observed that T2 well has constant thermal conductivity trend as it goes deeper. This is due to high amount of shale content which gives the constant trend)

Shale has low K due to the low conductivity of clay and mica minerals perpendicular to the layering of the flakes (Diment, 1968) and to the presence of many air-filled pores between flakes. For shales and soils with quartz content more than 35%, the clay content is usually less than 30%. For shales and soils with quartz content less than 35%, the clay may range from low to high in proportion.

With water saturating the pores of sandstone, the effect of raising the K with increasing content is much enhanced over air-saturated pores (Diment, 1968). In sandstone, clay content is usually low therefore the lowering of K by clay is estimated to be small in the sandstone while sandstone which has high quart content corresponds to high K. In general, the findings are similar to previous studies where high shale has low K and vice versa; however there is insufficient data of the mineral composition to relate it in terms of clay, mica and quartz composition.

4.2.4 Relationship between Thermal Conductivity and Geothermal Gradient

Depth is plotted against thermal conductivity and temperature. In general, thermal conductivity shows no significant trend to the depth however temperature is increasing with the depth (see FIGURE 16 and FIGURE 17).

Changes in temperature respect to the depth are known as geothermal gradient. From the profiles, at least two trends of geothermal gradient can be observed. These trends can be interpreted in term of heat transfer. High geothermal gradient means that the heat transfer is slow in the basin and vice versa. In general, low thermal conductivity corresponds to high geothermal gradient and high thermal conductivity corresponds to low geothermal gradient.

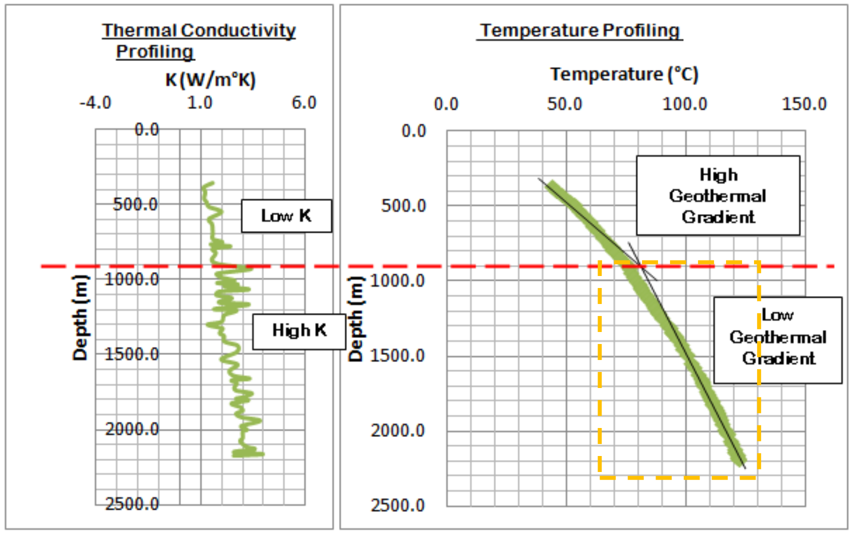


FIGURE 16: Thermal conductivity and geothermal gradient profiles at T1 well (for this well, when thermal conductivity is increased, geothermal gradient is decreased with a curvy shape)

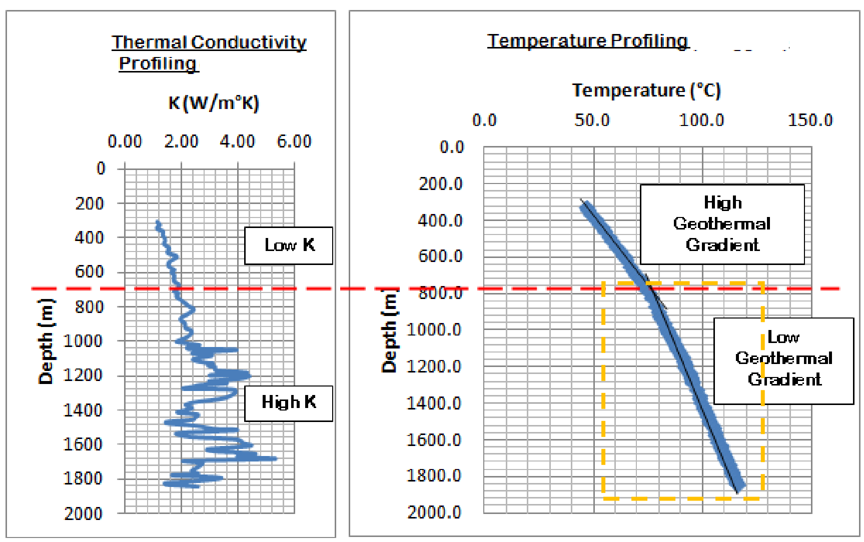


FIGURE 17: Thermal conductivity and geothermal gradient profiles at T2 well (for this well, when thermal conductivity is constant, geothermal gradient is descreased with a constant linear trend)

4.2.5 Relationship of Heat Flow and Thermal Conductivity

Depth is plotted against heat flow. This attempt is done to investigate the main factor which controls heat flow whether geothermal gradient or thermal conductivity. Heat flow is the exchange of thermal energy between physical systems depending on temperature and pressure, by dissipating heat (Wikipedia, 2014).

Findings show that the main factor affecting heat flow is thermal conductivity where the trend of heat flow is almost similar to thermal conductivity profiles for both wells (see FIGURE 18 and FIGURE 19). This is explained by the interaction between rocks when in contact known as conduction process. As depth increases, the rate of vertical loading also increases; representing higher compaction from the top sediments hence influencing the heat flow in the wells.

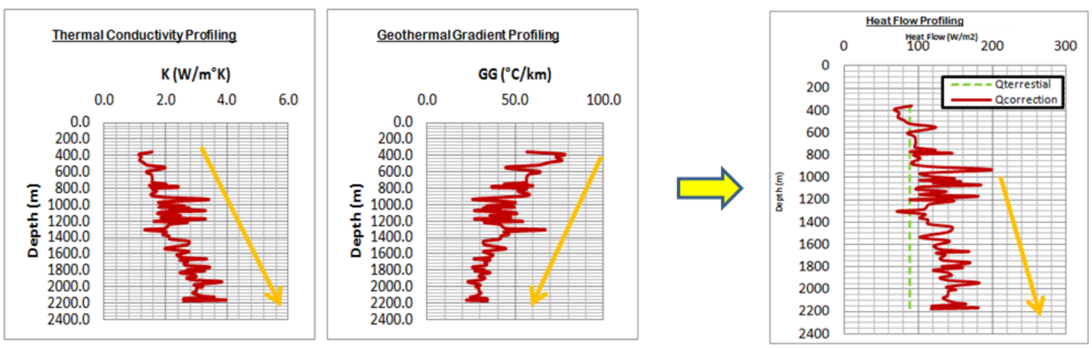


FIGURE 18: Heat flow profile at T1 well (for this well, when thermal conductivity is increased and geothermal gradient is decreased, an increasing heat flow trend can be observed)

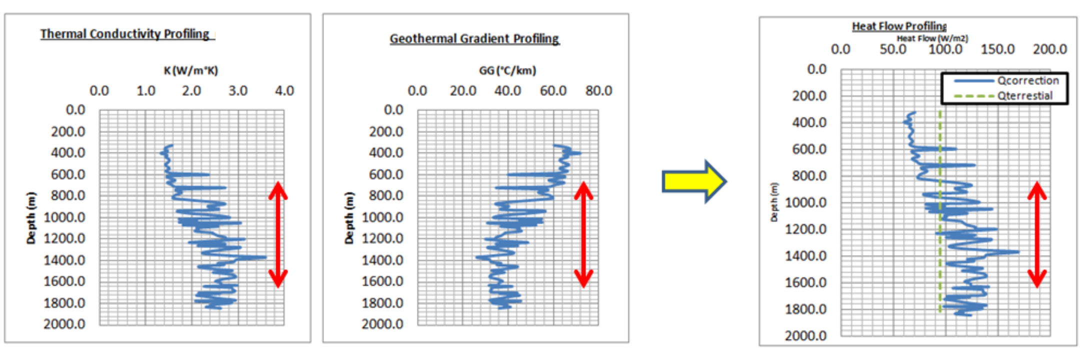


FIGURE 19: Heat flow profile at T2 well (for this well, thermal conductivity and geothermal gradient trends are constant, thus the heat flow profile shows a constant trend as well)

In general, there is no direct relationship between pressure and heat flow. However, as temperature increases, pressure is also affected. Hence, it can be said that both pressure and temperature distributions depend between each other which gives influence to heat distribution in the basin.

4.3 Overpressure Distribution

Based on pressure distribution, the overpressure zone occurs at depth 1800m until 2000m which is confined in Group E for T1 well and top of Group F for T2 well. Figure 20 illustrates the position of overpressure zone at both wells.

Due to data limitation, the overpressure distributions towards basin flanks are not well defined. However, assumption of the overpressure zone is made by using previous model at the basin-centre, which has dome and convex-up shape. It is assumed that there are two zone of overpressure; syn-rift sediments and post-rift sediments. This assumption is made based on thick shale deposits in group L and group F which acts as seal that hinders the pressure in the basin to be distributed.

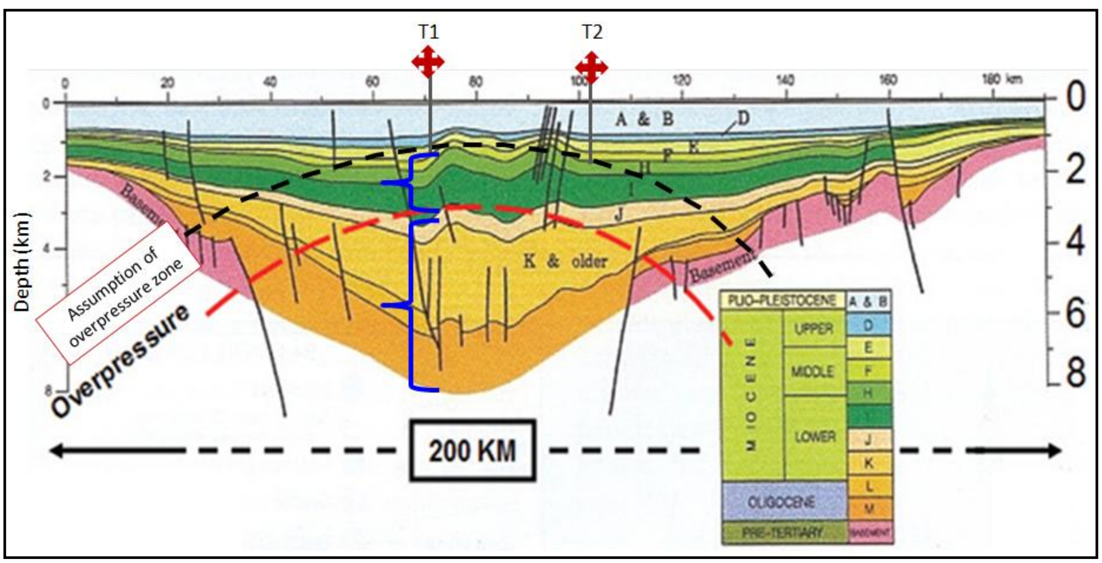


FIGURE 20: Overpressure zone in the Malay Basin (From the analysis, it is assumed that there are two zones of overpressure encountered in the Malay Basin which comes from syn-rift and post-rift sediments)

Overpressure can be generated by many mechanisms i.e. compaction disequilibrium (under compaction), hydrocarbon generation and gas cracking, aquathermal expansion, tectonic compression (lateral stresses), mineral transformation (such as smectite to illite formation) and hydrocarbon buoyancy (Swarbrick & Osborne, 1988). From the analysis, compaction disequilibrium is believed to be the main mechanism of overpressure in the Malay basin. Petrophysical data is used to determine the main mechanism. In this context, sonic and density-derived porosity are calibrated to show how data response at overpressure zone. From the profiles, it can be seen that the as depth increases, porosity and sonic transit time exhibit constant distribution which explains the occurrence of compaction disequilibrium in the basin (see FIGURE 21 and FIGURE 22).

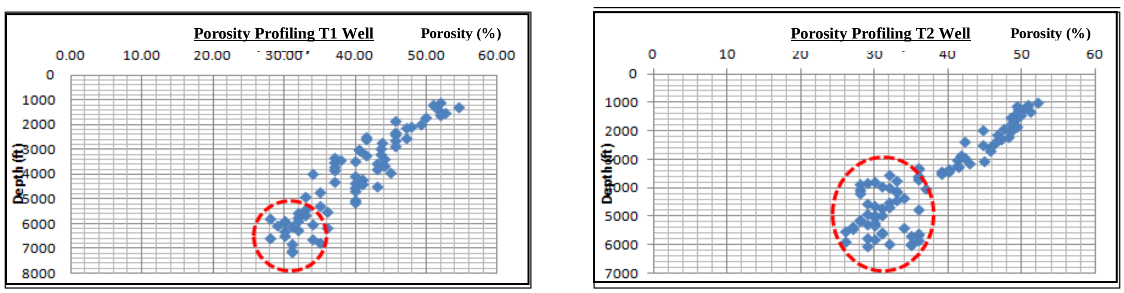


FIGURE 21: Porosity profiles at T1 well and T2 well (At normal compaction, porosity decreases exponentially with the depth. However, at porosity reversal section (shown by red circles), undercompaction occurs and overpressure generates. At this depth, porosity and pore pressure are higher compared to the normally compacted section. The starting point of porosity reversal is classified as top of overpressure.)

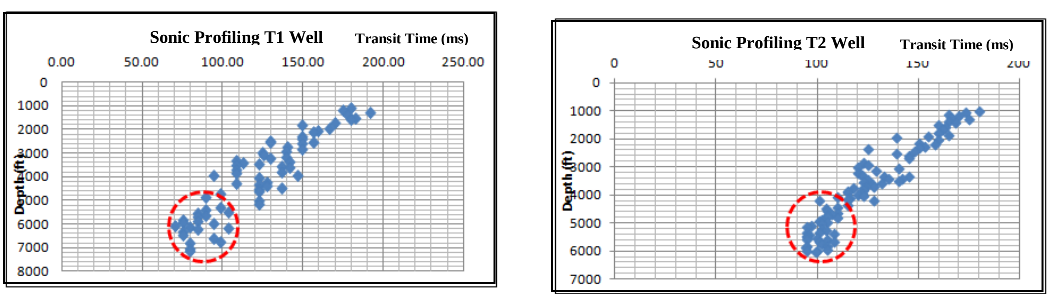


FIGURE 22: Sonic transit-time profiles at T1 well and T2 well (It is accepted that when overpressure zone is encountered, the sonic velocity is reduced since there is a

reduction in effective stress on the rock. This is due to the fact that sound travels slower in a less compacted rock (shown by red circles).)

Using PetroMod software, two models are developed to present the conditions at exploration wells during basin extension (see FIGURE 23 and FIGURE 24). This is because during basin extension (Miocene age), high rate of sedimentation filled the basin which leads to high burial and compaction. From that, the fluid in the pore space is forced to move out to achieve the equilibrium state. At this time, the vertical load increases and porosity decreases. If the permeability is slower compared to the rate of vertical loading, the effective pore fluid will support additional load and result to the overpressure generation.

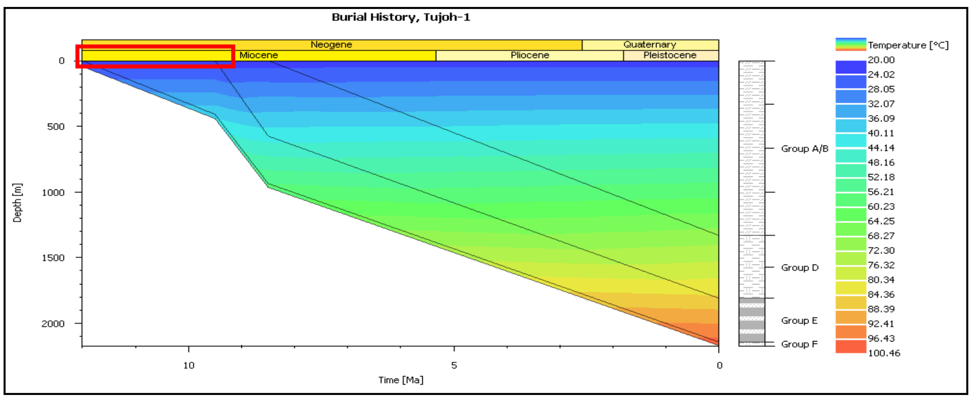


FIGURE 23: Burial History of T1 well (The box indicates high sedimentation occurs during Miocene age which leads to high burial rate)

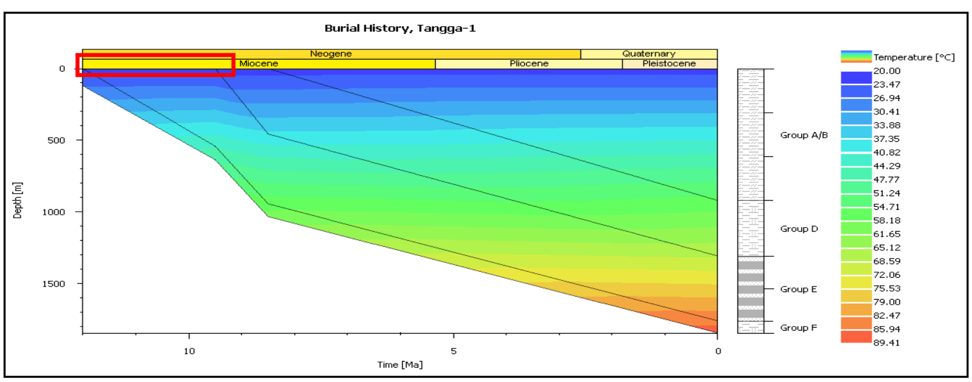


FIGURE 24: Burial History of T2 well (The box indicates high sedimentation occurs during Miocene age which leads to high burial rate)

4.4 Fieldwork Interpretation

Six different locations are investigated to examine the reservoir properties in the Kelantan Delta. These locations represent two parts; eastern and western of the delta. In each location, soil samples are taken. However, only one location in the eastern part, Hotel Perdana will use borehole data acquired from previous study (see TABLE 4).

TABLE 4: Location of fieldwork in the Kelantan Delta

Part	Location	Latitude (Degree)	Longitude (Degree)
Eastern	Pantai Mek Mas	6.213962	102.245978
	Hotel Perdana	6.120742	102.241468
	Kampung Kor	6.015583	102.236152
Western	Pantai Sri Tujuh	6.218305	102.135077
	Kampung Cherang	6.165035	102.148087
	Kampung Tok Sidi	6.098960	102.106750

Lithostratigraphic section is a stratigraphic column that is correlated based on lithology. Two lithostratigraphic sections from *Jabatan Mineralogi dan Geosains* (JMG) Malaysia are used to study the reservoir properties in Kelantan Delta. These cross-sections cover eastern and western parts of the study location known as D-D' and E-E' (see FIGURE 25 and FIGURE 26).

Lithology map is generated to show different rock types and its source of sediments (see FIGURE 27). There are six different rock types in the Kelantan area. It can be deduced that the main source of sediments comes from Kelantan River; consists of clay, sand, peat and minor gravel distributions. As Kelantan coast is exposed mainly to South China Sea wave, the geomorphology of the coast is obstructed by mechanical factors. Thus, it is believed that the sediment contents at the study locations vary depending on the environmental setting and mechanical factors that transports the sediments. Simulations by using PetroMOD are conducted to interpret the reservoir quality in the Kelantan delta at several locations.

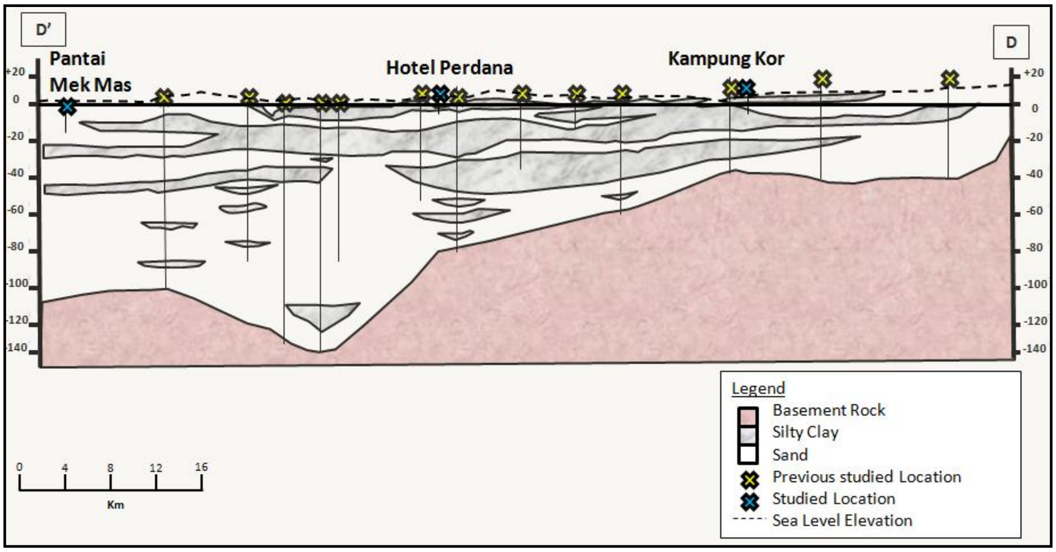


FIGURE 25: Cross section D-D'; this cross section covers the eastern part of Kelantan Delta along Kota Bharu with a total of 27 wells from hydrology analysis. From the lithostratigraphic section, the lithology for Hotel Perdana and Kampung Kor are impermeable layer which can be clay or siltstone while Pantai Mek Mas is a sand layer (modified after JMG, 2011).

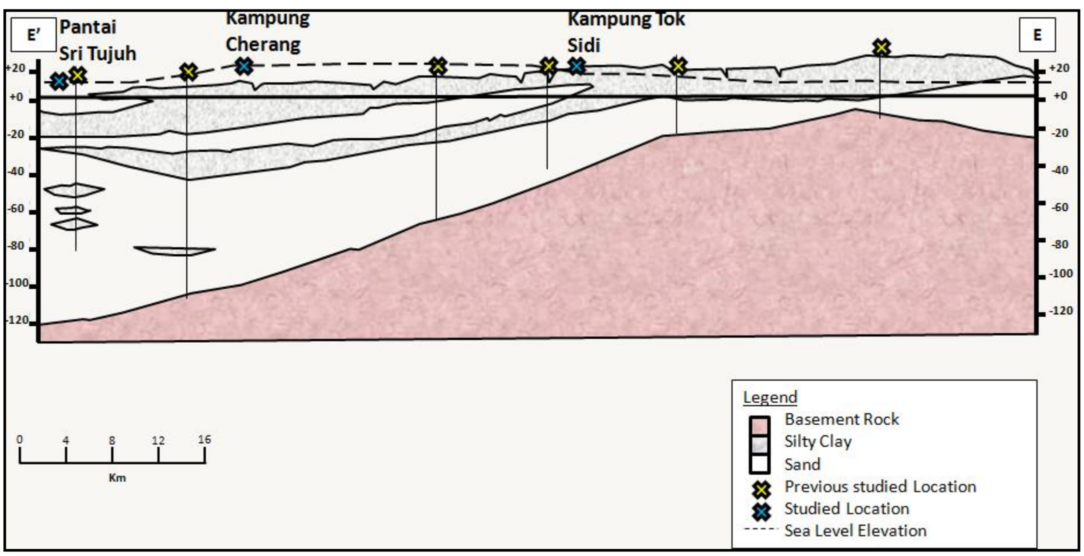


FIGURE 26: Cross-section E-E'; this cross section covers the western part of Kelantan Delta. The sediments distribution is varied in each sample location; Pantai Sri Tujuh is sandy area, Kampung Cherang is silty area and Kampung Tok Sidi is mud/shale area (modified after JMG, 2011)

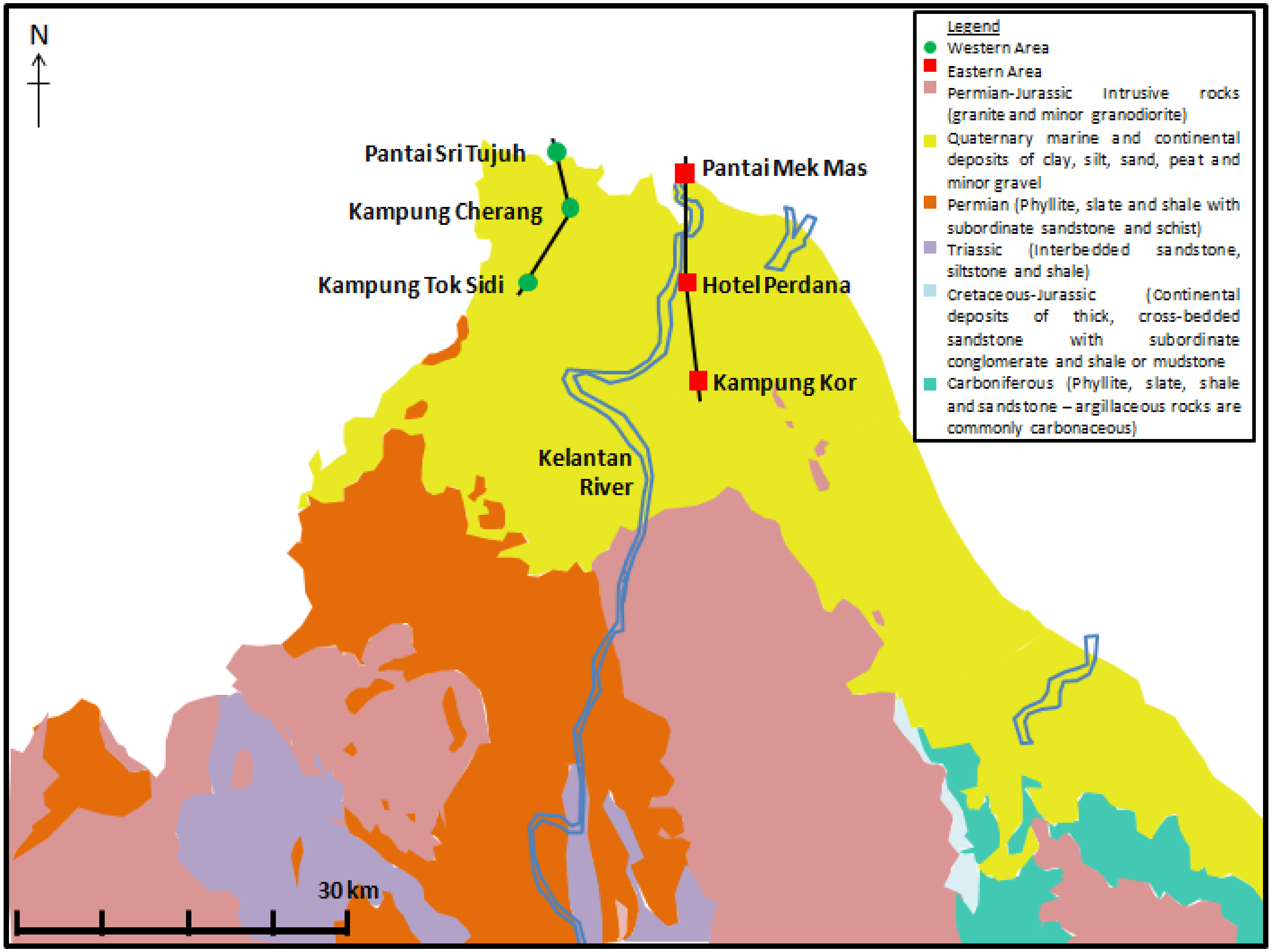


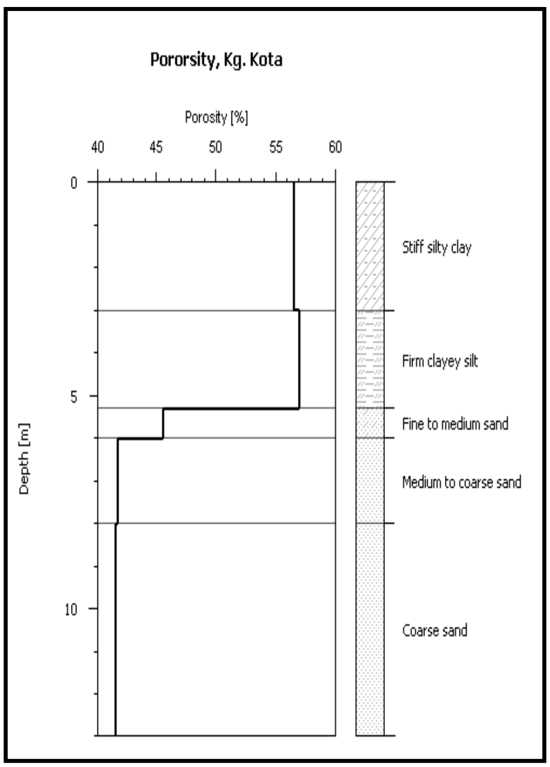
FIGURE 27: Lithology Map of Kelantan Delta; the delta is built up from continental deposits along the inner margin and marine deposits from the outer margin (indicated by the arrows)

Fields observation:

 Erosion Surface (Pantai Sri Tujuh)	 Mud Crack (Kampung Tok Sidi)
 Three borehole data is recorded at Hotel Perdana; one of its borehole sample position	 Different strata layers observed which indicates changes in sea level (Pantai Mek Mas)
 Silty Sand (Kampung Cherang)	 Silty sand (Kampung Kor)

Based on the simulations, it can be observed that Kampung Kota and Kampung Telok have potential properties to become good reservoir. The porosities in these areas range from 40% to 58% at shallower and deeper parts. These values are high which are not possible to occur in the Malay basin.

From the trends, it can be seen that as depth increases, the porosity decreases. This happens due to compaction factor. High sedimentation from on top layers leads to high compaction factor. Thus, the pores collapse which reduces the porosity at deeper part. While, at shallower part, the porosity values are high even though the area is clayish sediments. Clay has fine grains which makes the pores spaces between them to be low. However, as clay is located in shallower part, it is assumed that the area composes of uncompacted clay which gives high porosity values.



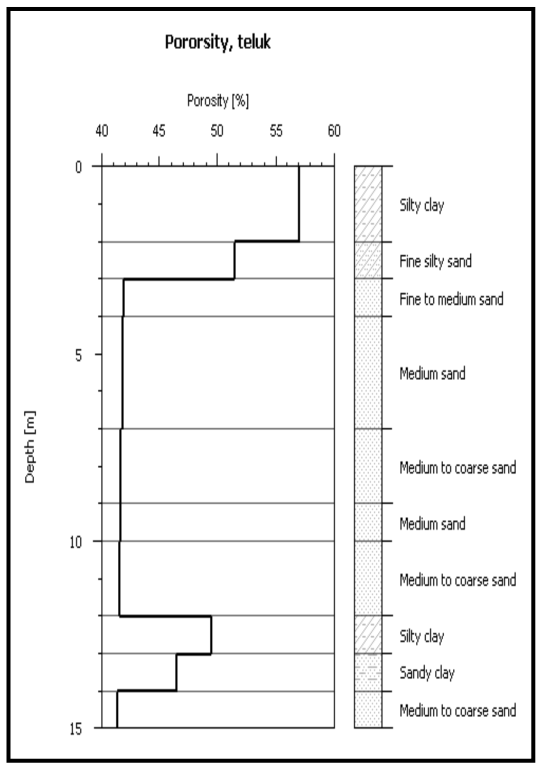


FIGURE 28: Porosity profiling at Kampung Kota and Kampung Telok (At Kampung Kota, it is observed that porosity is constant at 6m onwards while at Kampung Telok, there is fluctuations in the porosity ranges depend on the lithology they encountered)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, data from two exploration wells are used to present the central of the Malay basin. Well logging data is used as primary input for the research by analyzing the log motif and related it to the reservoir properties. Further, discussion on overpressure distribution is done.

In term of reservoir quality, tidal bar and mouth bar which are developed within distributary channels, along delta fronts and in the outer parts of estuaries, have moderate to good reservoir qualities. This is due to the fact that the reservoirs have high lateral and vertical homogeneity. It is concluded that the main control mechanism of overpressure in the central basin is due to disequilibrium compaction. It is believed that the regional shale from group F contributes to the high amount of pressure in the compartment.

5.2 Recommendation

Throughout the research work, several approaches could not be performed due to limitation in terms of time, data and knowledge. Therefore, in the future work, it is hope that the recommendations suggested should be considered:

1. The data used for the research only focuses the central of the basin. For this reason, the author could not justify the trend of overpressure zone at the basin flanks. However, it is assumed that the overpressure zone occurs at deeper depth or older sediments compared to the centre of the basin.

2. Reservoir quality in this research is not studied in details. The author only concentrates the relationship of pore pressure with other thermophysical properties in order to examine the overpressure distribution.
3. Thermal conductivity derived in this research is not corrected to fluid and temperature due to limitation in data. Therefore, the resulted thermal conductivity has small effect to the interpretation of thermal conductivity with other thermophysical properties. However, if corrections are made, the results are more accurate.

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APPENDICES

APPENDIX 1

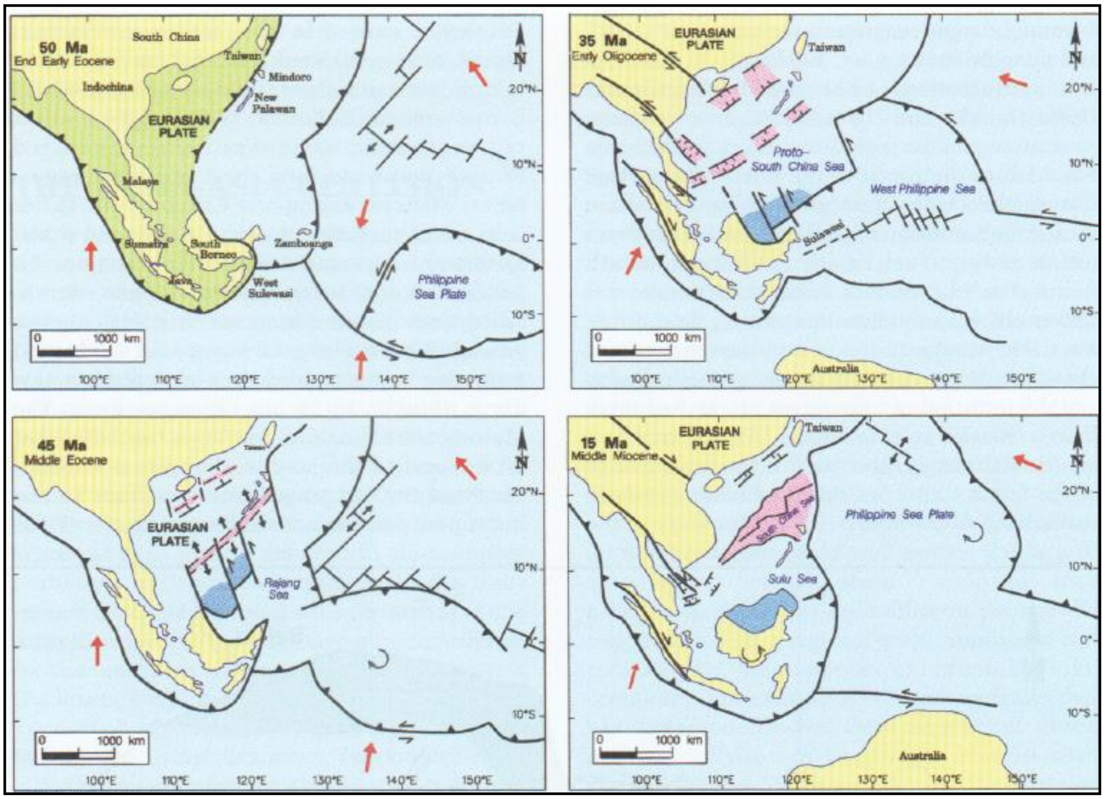

FIGURE 29: Schematic reconstruction of the tectonic evolution of Southeast Asia since the Eocene (Hall, 1997). 50 Ma – SE Asia formed by Sundaland, surrounded by active margins. 45 Ma – Rifting of the South China margin created extensional basins. 35 Ma – Further extension in South China margin and central Sundaland caused collision between microcontinental blocks (blue areas) with northern Borneo to close the Rajang Sea. 15 Ma – South China Sea spreading completed; dextral reactivation of strike-slip zones and the arrival of Australia from the south resulted in basin inversion across Sundaland (Petronas; 1999).

APPENDIX 2

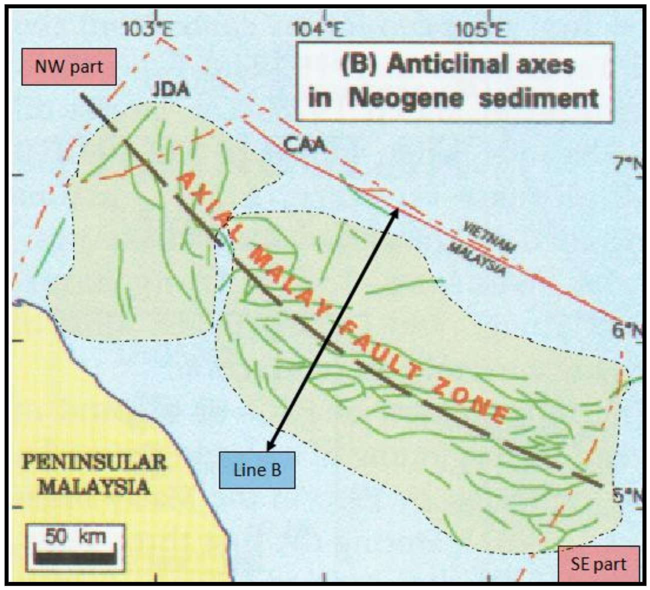

FIGURE 30: Faults direction in the Malay basin; the dotted boundaries represent NW and SE parts (modified after Petronas, 1999)

APPENDIX 3

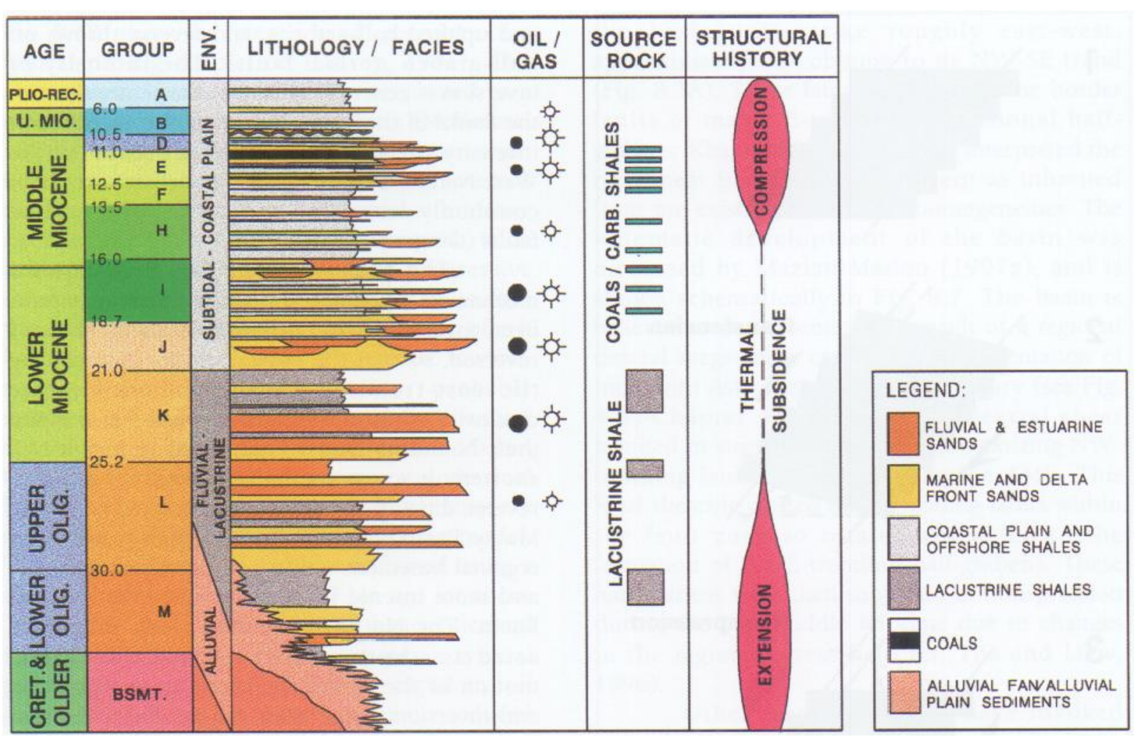

FIGURE 31: Stratigraphy nomenclature by ESSO (EPIC, 1994)

APPENDIX 4

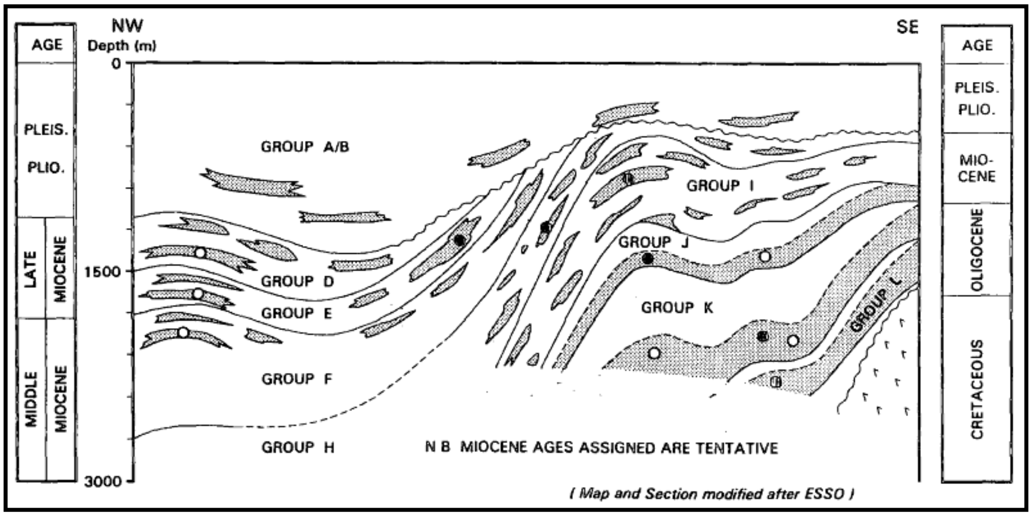

FIGURE 32: Cross section of NW to SE of the Malay Basin showing regional unconformity (Wan Ismail, 1993)

APPENDIX 5

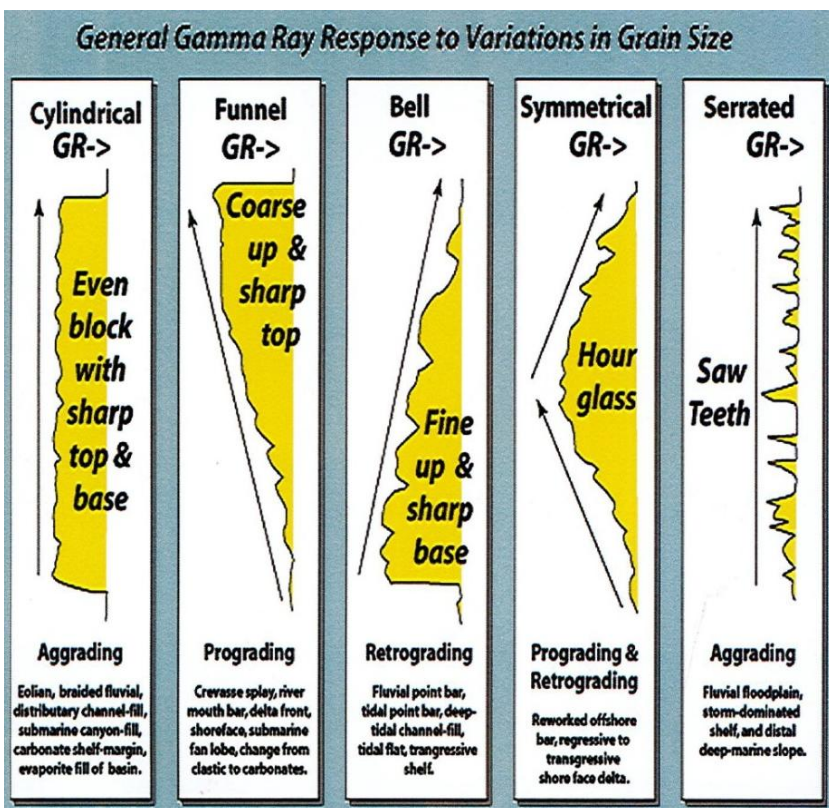

FIGURE 33: Log Scheme (Kendall, 2003)

APPENDIX 6

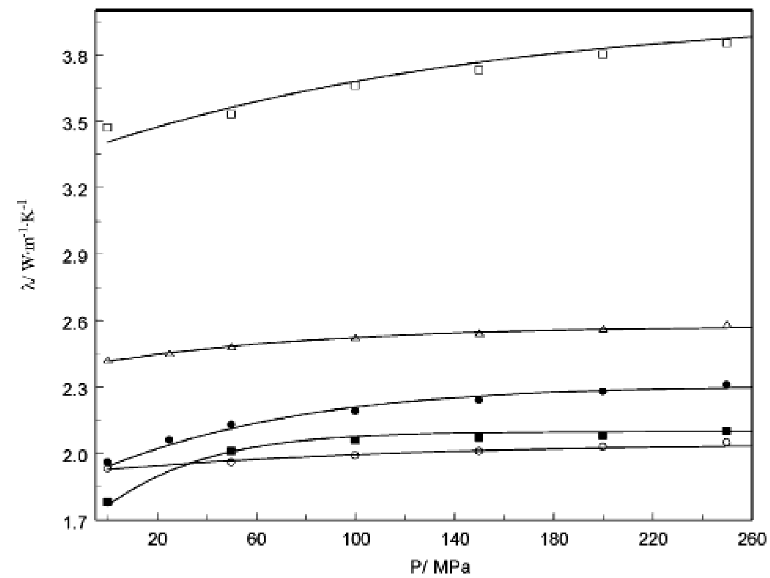

FIGURE 34: Comparison of experimental pressure dependence on the thermal conductivity for different rocks types at selected temperature; from the top amphibiolites, proxene, granulite, limestone and sandstone (Abdulagatov, 2006)

APPENDIX 7

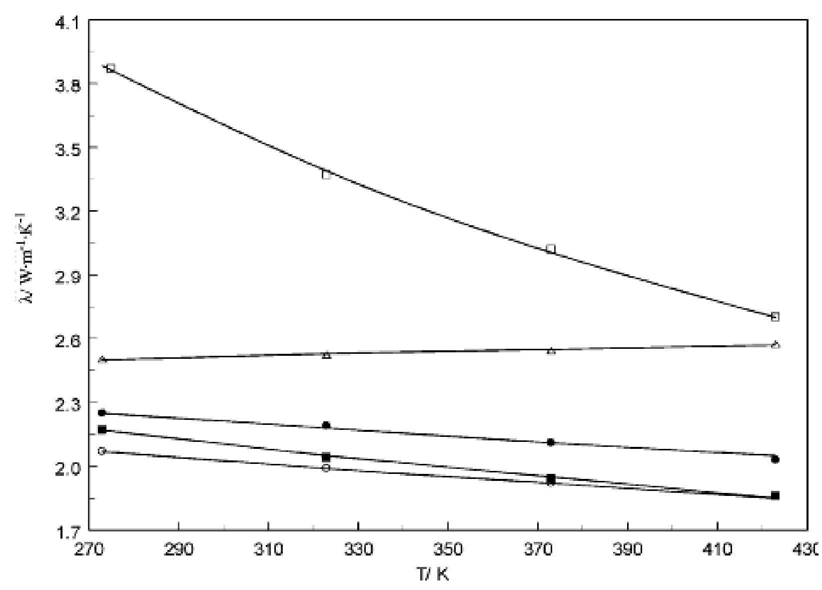

FIGURE 35: Comparison of experimental temperature dependence on thermal conductivity for different rocks types at 100 MPa; from the top amphibiolites, proxene, granulite, limestone and sandstone (Abdulagatov, 2006)

APPENDIX 8

TABLE 5: Gantt chart for Final Year Project I

No.	Progress/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of FYP Topic								MID-SEMESTER BREAK							
2	Preliminary Research: Project Background and Literature Review															
3	Fieldwork and Continuation of Research Work															
4	Submission of Extended Proposal Defence on 23rd February, 2014															
5	Proposal Defence Evaluation on 12th March, 2014															
6	Submission of Interim Report on 14th April, 2014															

APPENDIX 9

TABLE 6: Gantt chart for Final Year Project II

No.	Progress/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Continuation of Research Work															
2	Submission of Progress Report on 1^{st} July, 2014															
3	Pre-Sedex Evaluation on 17^{th} July, 2014															
4	Submission of Technical Paper and Dissertation (Soft Bound) on 7^{th} August, 2014															
5	VIVA Evaluation on 12^{th} August, 2014															
6	Submission of Dissertation (Hard Bound)															