CHAPTER 1.0: INTRODUCTION

1.1 Introduction

In sandstone reservoirs, important characteristics such as porosity and other properties are determined by a combination of depositional and diagenetic effects. It is critical to know the distribution of these properties within a reservoir rock in order to achieve the maximum efficiency in reservoir management for hydrocarbon production. Reservoir characterization is a complex process to identify reservoir properties by establishing interdisciplinary relationships from pore to basin scale (Schatzinger & Jordan, 1999). For oilfields in Miri Sarawak, a quantitative work in characterizing and evaluating the reservoirs is needed to understand the complex reservoir characteristics in order to achieve the objectives of the study where to integrating the sedimentological and petrophysical properties to perform good reservoir characteristics.

1.2 Project Background

Sandstones are very important as reservoirs for oil and gas; about 50% of the world's petroleum reserve is estimated to occur in sandstones (Berg, 1986). The purpose of studying the reservoir sedimentological characteristics, petrophysical and rock physics properties of sandstones from Miri, Sarawak is to investigate and determine the rock and reservoir properties of different types (facies, depositional) of sandstones.

Understanding the properties of sandstones is essential in the exploration and production of hydrocarbon from the subsurface sedimentary strata as these properties strongly influence their reservoir qualities. Sandstones are deposited within sedimentary environments ranging from continental alluvial settings, to marginal coastal areas which are affected by riverine, waves and tidal processes, to deep submarine region. The primary properties of sandstones (texture, composition, sedimentary structures, morphology and stratigraphic heterogeneity) are largely determined by the source materials and by the environment of deposition (Berg, 1986; Morse, 1994).

This study on the sedimentological (facies, grain size) and reservoir petrophysics properties (grain size, porosity, permeability) of sandstones were conducted on the sedimentary rocks belonging to the Hospital Road, Miri. Sarawak.

1.3 Significant of Study

Reservoir characterization is the building block of a geologic and engineering model that describes the reservoir's internal architecture and the distribution of hydrocarbons. The study should incorporate all geologic scales of heterogeneity-from gigascopic basin-scale characteristics to microscopic pore-level characteristics. The internal architecture delineated is based on the integration of geologic character with measured engineering parameters. This integration should result in a study that describes all salient fluid-flow paths and barriers. The distribution of hydrocarbons is also a critical element in a reservoir characterization model and follows from the determination of reservoir architecture. Identifying the location within the reservoir of both the initial and remaining hydrocarbon resource allows the study to be applied as a tool for assessing reserve growth potential. However by applying the proper reservoir characterization methodology, a study can be constructed that optimizes and integrates all the data and thus facilitates the identification of reserve growth potential.

The study also is to examine how different data can be intergrate to examine relationship between petrohysical properties and different sedimantatry features of the Miri formation especially in Jalan Hospital sandstone reservoir.

The idea behind this study was first to compare many different methods to characterize and model reservoir heterogeneity based on geologic, geosciences, and engineering data, and then to integrate the good results. As the data derived from the outcrop studies involves sand body geometry, facies characterization and petrophysical are then will used to examine reservoir characterization.

The area of study will be considered of as an extended onshore part of West Baram Delta where Hospital Road was selected as the project field. Based from the journal, the total area is composed only less than one third of the total Baram Delta Province, which is known as the Miri Oilfield.

1.4 Problem Statement

In order to evaluate the performance and estimate the hydrocarbon production, the main problem occurs when no systematic works which integrates geological information and petrophysical data has been done. The importance of interpreting the relationship between geology and petrophysical data is recognizable since both subjects are related to each other. Previous studies have shown that the geological properties such as sedimentary facies, lithology structure and texture composition of rock is generally related to the heterogeneity of reservoir. It gives significant impact in term of the flow pattern and volume capacity of reservoir. For example, the physical, chemical and biological processes in specific depositional environments and resulting depositional facies determine many attributes that are directly or indirectly related to hydrocarbon generation, migration, entrapment and reservoir productivity (Fisher and Galloway, 1983). However, further systematic studies regarding relationship between sedimentary facies characteristics and petrophysical properties must be conducted particularly in Miri. Therefore, the study will provide two key solutions:

i. Developing the relationship between sedimentary facies and lithology of rock and petrophysical properties to describe how reservoir heterogeneity affects flow of hydrocarbons.
ii. Giving detailed description of Miri field reservoir characteristics through study of formation geological setting and petrophysical properties which further can be developed as reference tool for production in Miri field.

The heterogeneity of continental sandstone reservoir has a great difficulty for understanding and smoothly developing oil field, but also provides many beneficial material bases for adjustment at later period

1.5 Objectives

The ultimate objectives of this study are to characterize and quantify the Miri reservoirs by analysis and integrating sedimentary facies characteristics and petrophysical properties. The objectives will be achieved by following:

- To study Miri formation especially in Hospital Road.
- To identify various scales of heterogeneity in sandstone reservoir of Hospital Road.
- To investigated the geological factors affecting reservoir heterogeneity.
- To integrating geological (sedimentary facies) and petrophysics properties.

At the end of this study, the result in this project may useful as a reference for oil exploration and production in Miri field for further activities.

1.6 Scope of Study

The project focuses on the reservoir rock outcrop of Miri field and the study have several stages were divided in order to achieve the objectives of this project. Reservoir rock outcrop Hospital Road has been chose for identifying its characteristics as to be a potential scales in sandstone reservoir. This project will be done according to time frame and planned scheduled. This project will involve several petrophysics properties of the Miri reservoir rocks especially Hospital Road. Then the scope will narrowed down and specifically into laboratories testing to compare with the reference material.

The scope of the study will focus on the characterization of the heterogeneity of Hospital Road outcrop. The test will be conducted by using several equipments available in UTP.

1.7 Study Area (Hospital Road)

The study of Hospital Road outcrop involves field works and laboratory work as the field trip took placed on January 2011. The study was conducted on onshore sedimentary rocks exposed in Northeastern Sarawak, where the area of the outcrop is located at Hospital Road, Miri. In the geological view, the study area is considered as an extended onshore part of Baram Delta province adjacent to the West Baram Line.

Figure 1: Outcrop of Hospital Road, Miri, Sarawak (Picture taken during field trip in January 2011)

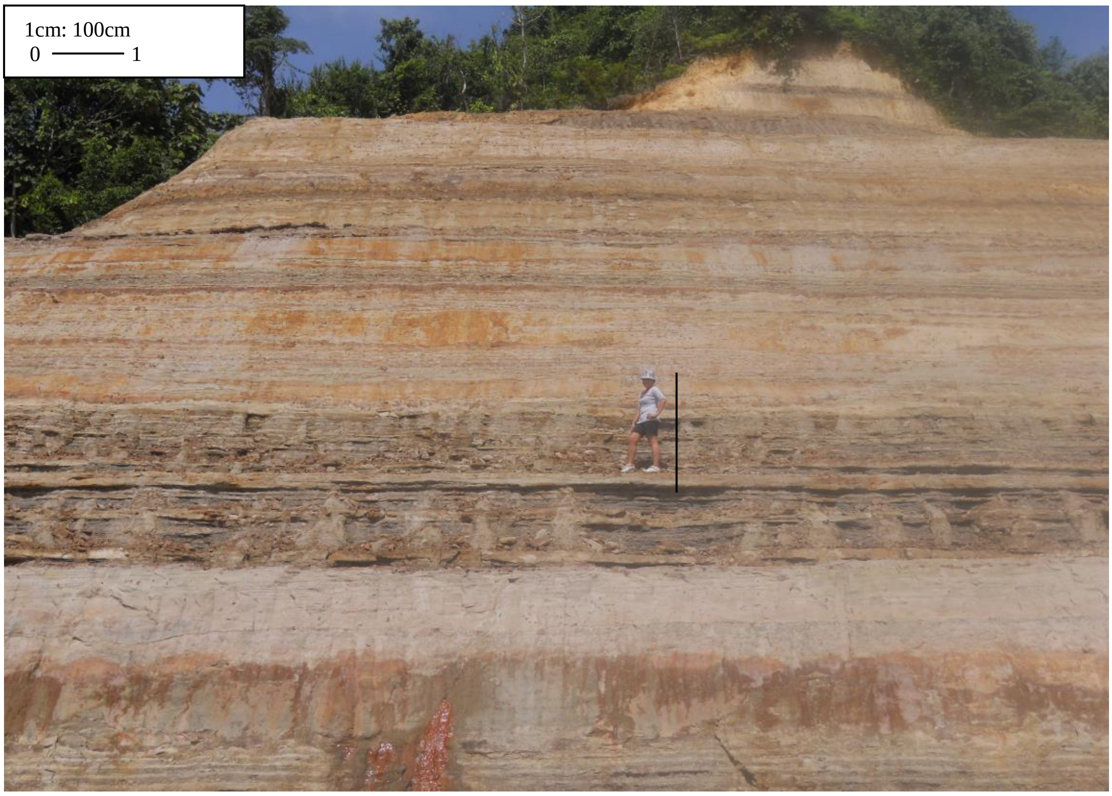

Figure 2: Upper part of Hospital Road outcrop (Picture taken during field trip in January 2011)

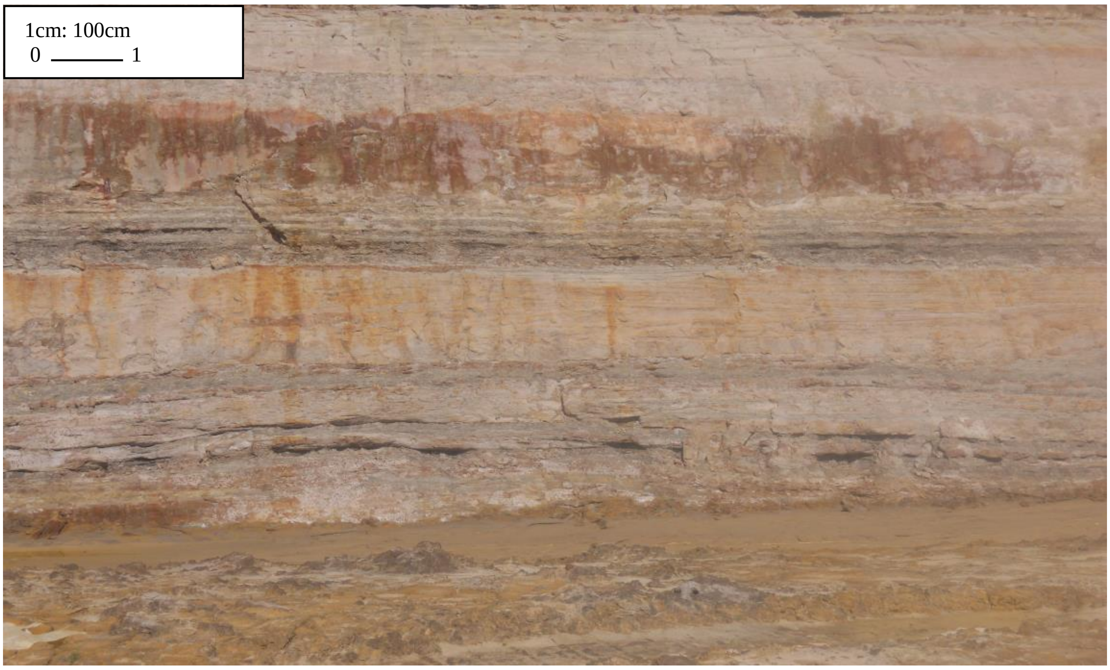

Figure 3: Lower part of Hospital road Outcrop (Picture taken during field trip in January 2011)

1.7.1 The background of Miri Formation

There were several outcrops (rocks) exposed around the Miri town which belongs to the Middle Miocene Miri Formation, are the uplifted part of the subsurface, oil bearing sedimentary strata of the Miri oilfield and possibly used in research for offshore field. The subsurface successions have been explored since early 19^{th} century where modern western oil technology was only employed in 1899 and the first modern production well, the Miri-1 came into production in 1910 (Tan et al, 1999) Liechti et al. (1960) described the formation as a predominantly marine succession, based on observations of outcrops of the Miri Anticline and examination of subsurface material from the Miri oil field. The basal contact with the underlying Setap Shale formation is a gradual transition from a succession downward into a predominantly argillaceous succession. Based on lithological differences and small benthonic Foraminifera assemblage, Liechti et al. (1960) and Wilford (1961) divided the formation into a Lower and Upper unit.

The maximum total thickness of Miri Formation estimated is over 6,000 feet. The difference between the Lower and the Upper Miri is not clear enough to map the boundary on lithology alone. The Lower Miri consists of well defined beds of sandstones and shales, with the shales slightly prevailing. These lower unit shales out down wards to merge gradually into the underlying shale formation. The Upper Miri Formation is more sedimentary rocks. It consists of rapidly recurrent and irregular sandstone-shale alternations, with the sandstone beds merging gradually into clayey sandstone and sandy or silty shale. From the identification of marine microfauna and lithological characteristics, Liechti *et al.* (1960) concluded that these sediments were 7 deposited in a littoral to inner neritic shallow marine environment. The beds of Miri formation are gently to moderately folded. The Miri anticline has a northeasterly trend. Its north-west flank consists of overthrusted blocks, while the structurebis cut by normal faults (Wilford, 1961).

1.7.2 Geological background of Miri field

The West Baram Delta is characterised by the deposition of a northwest upward prograding delta since Middle Miocene times. Periods of delta out building were separate by rapid transgressions, represent by marine shale intervals that form the base of eight sedimentary cycles. The regressive sequences of each depositional cycle grade northwest from coastal fluviomarine sands to marine shale. The depositional cycles become successively nature of the shelf systems. The geological evolution, stratigraphy, and trap configuration of the Baram Delta are well documented by geologists from Shell and other oil companies who have worked in the area.

Since the middle Miocene, the Baram Delta has been subsiding relative to the more stable Central Luconia and Balingian provinces to the west. Within the Baram Delta, Major increases in sedimentary thickness occur across growth faults, which generally trend Northeast-Sourthwest direction, on trend with the West Baram Line to the west.

The West Baram Delta comprises up to 9-10 km of Miocene to recent silicilastic sediments derived from the south-southeast, along the trend of the present day Baram river, and from the west and south east across the West Baram Line.

(Reference: Denis, N.K.T., Abdul Hadi, A.R., Azlina, A., Bait, B. & Chow, K.T., 1999. Chapter 13 – West Baram Delta. In: PETRONAS, *The Petroleum Geology and Resources of Malaysia*, PETRONAS (Petroleum Nasional Berhad), p. 293-342.)

1.8 History of Onshore and Offshore West Baram Delta

1.8.1 Onshore West Baram Delta

The West Baram Delta is the western part of the Upper Tertiary Baram Delta province which is roughly triangular in shape, with its apex occurring onshore and centred in Brunei and the north eastern coastal area of Sarawak.

Exploration for oil in the Baram Delta commenced in 1909. The first exploration well, Miri-1 was drilled in 1910. This well resulted in the discovery of the Miri Field that ultimately produced about 80 million barrels of oil before it was abandoned in 1972.
A total of 27 exploration and appraisal wells were drilled by Shell until the concession was relinquished in 1981. Except for Miri-1, none of the other wells encountered significant hydrocarbons. Most of these exploration wells were located based on surface geology and/or single fold seismic.

In 1987, Malaysian Baram Oil Development Company (MBODC, as operator) and PETRONAS Carigali were awarded a PSC to explore Block SK14. MBODC acquired 738 km of 2D seismic and drilled 5 wells, resulting in the Asam Paya oil discovery. The acreage was relinquished in 1993 without development of the Asam Paya field.

In 1990, Carigali and others operator (Idemitsu, AGIP) were awarded Block SK17. A total of 1018 km of 2D seismic was acquired and two exploration wells drilled, without success. The block was released in 1995.

(Reference: Denis, N.K.T., Abdul Hadi, A.R., Azlina, A., Bait, B. & Chow, K.T., 1999. Chapter 13 – West Baram Delta. In: PETRONAS, *The Petroleum Geology and Resources of Malaysia*, PETRONAS (Petroleum Nasional Berhad), p. 293-342.)

1.8.2. Offshore West Baram Delta

The first offshore exploration well (Siwa 1) was drilled in 1957 from a fixed platform constructed in shallow water. Unfortunately the well did not encounters any hydrocarbons. The first offshore field was discovered in 1963 by the Baram-1 well drilled with the jack up rig orient explorer. This success led to an increase in activities and opened the way further discoveries in the offshore Baram Delta during late 1960s and 1970s. The earlier exploration play was the Cycle V and VI topset sands in large anticlinal features and drilling was terminated upon encountering overpressures. Recent exploration effort resulted in more gas discoveries in footwall closures along the nose of anticlinal features.

From 1955 to 1988 a total of 11 oil and gas discoveries were made by Shell in the offshore West Baram Delta. Siwa North-1 was the last well drilled before final released in 1988.

After late 1980s, lots of new fields was discovered and producing oil which is namely, Bakau, Baram, Baronia, Betty, Bokor, Fairley-Baram, Siwa, Tukau and West Lutong fields under Baram Delta Operations (BDO). Carigali (Operator) and Shell was awarded the PSC agreements. Most of the PSC agreements in West Baram Delta fields were awarded to Carigali and Shell as the operator.

On 1990s, Carigali and Shell were awarded the deepwater Block E under the deepwater PSC terms. Shell acquires a total of 5200 km of long cable 2D seismic data in 1996 and 1997. Evaluation of the acreage is in progress.

(Reference: Denis, N.K.T., Abdul Hadi, A.R., Azlina, A., Bait, B. & Chow, K.T., 1999. Chapter 13 – West Baram Delta. In: PETRONAS, *The Petroleum Geology and Resources of Malaysia*, PETRONAS (Petroleum Nasional Berhad), p. 293-342.)

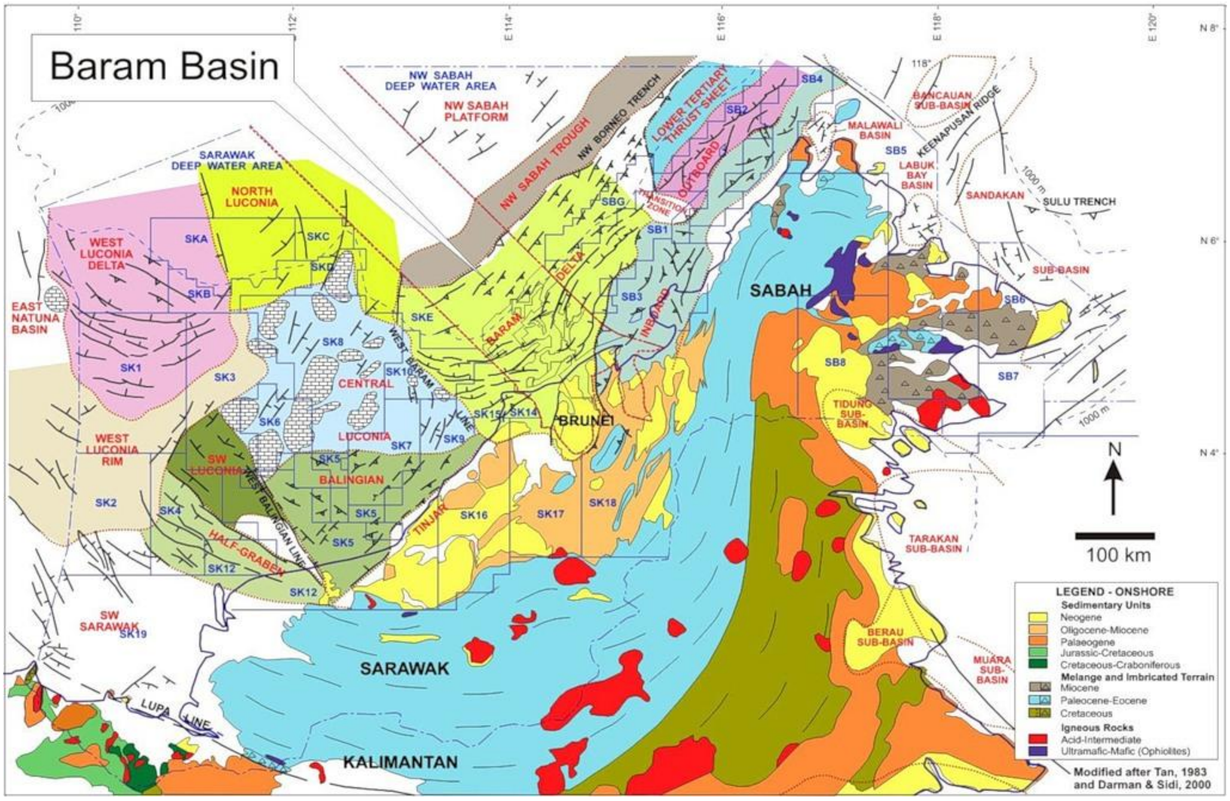

Figure 4: Baram Basin in Miri, Sarawak (Courtesy http://geoseismic-seasia.blogspot.com)

1.9 Dissertation of Final Report

This report consists of five chapters. Chapter 1 is the introduction of final year project including the significant and objectives of study. Geological background on study area is also presented in this chapter to give insight and basic description on geology evolution and history of Miri field. Chapter 2 is the literature review on heterogeneity of sandstone reservoir and facies characterization. Details of petrophysical properties and related works are addressed in this chapter. Chapter 3 focuses on methodology and the methods used in this work. Formulas and related calculation, sampling and laboratory analysis are discussed in this chapter. Chapter 4 is the result of investigation for this project and discussion for this work, by integrating depositional facies characteristic and petrophysical properties to understand heterogeneity of reservoir. Finally, Chapter 5 includes the conclusion and recommendation for further study.

CHAPTER 2.0: LITERATURE REVIEW

2.1 Introduction

The goal of this study is to describe, characterize and quantify the reservoir properties of Tertiary sandstones of Hospital Road, Miri by integrating the sedimentary facies characteristics and petrophysical properties.

In general, hydrocarbons are complex organic compounds generated and kept within sedimentary rock because of their more pore and permeable. These types of rocks are the main target in petroleum explorations from which hydrocarbons are extracted and produced.

One of the most important groups of sedimentary rocks is the sandstones. Sandstones frequently form major aquifers and petroleum reservoirs, with predictable geometry and reservoir performance compared to carbonates. This is because sandstones are more uniform in their facies characteristics and petrophysical properties. The reservoir is an essential element of the petroleum system and it must be able to accommodate a significant volume of fluids to obtain its hydrocarbon charge and be produced (North, 1985). Most of the sandstones reservoir are heterogenous and petrophysically anisotropic. Sedimentology and petrophysics methods are integrated to understand these reservoir characteristics from pore to tectonic and basin scales.

To understand how the reservoir properties are related to the stratigraphic sequences and depositional processes, their sedimentological and petrophysical characteristics must be known. Integrated sedimentological and petrophysical methods in characterizing sandstone reservoirs had been carried out by many authors (Abdul Hadi, 1995; Castle & Byrnes, 2005; Lima & De Ros, 2003; Reifenstuhl, 2002; Shirley *et al*., 2003; Walton *et al.*, 1986; Westphal *et al*., 2004).

2.2 Reservoir Rock and Reservoir Sandstones

All the oil created by the source rock won't be useful unless it winds up being stored in an easily accessible container, a rock that has room to "suck it up". A reservoir rock is a place that oil migrates to and is held underground.

A rock with pores is referred to as porous. This means it has tiny holes through which oil may flow. Reservoir rocks must be porous, because hydrocarbons can occur only in pores (Walton et al, 1986). A reservoir rock is also permeable. That means its pores are connected. If hydrocarbons are in the pores of a rock, they must be able to move out of them. Unless hydrocarbons can move from pore to pore, they remain locked in place, unable to flow into a well. A suitable reservoir rock must therefore be porous, permeable, and contain enough hydrocarbons to make it economically feasible for the operating company to drill for and produce them. (Walton et al, 1986)

Sandstone has plenty of room inside itself to trap oil, just like a sponge has room inside of itself to soak up spills in your kitchen. It is for this reason that sandstones are the most common reservoir rocks.

2.3 Sandstone Reservoir

The interrelationship of reservoir porosity, permeability, thickness, and lateral distribution determines reservoir system quality. Sandstones and carbonates are the examples of dominant reservoir rocks. Diagenesis alters the original pore type and geometry of sandstone and therefore controls its ultimate porosity and permeability. Early diagenetic patterns correlate with environment of deposition and sediment composition. Later diagenetic patterns cross facies boundaries and depend on regional fluid migration patterns. Effectively predicting sandstone quality depends on predicting diagenetic history as a product of depositional environments, sediment composition, and fluid migration patterns. (Tucker, 1981; Berg, 1986)

Understanding the properties of sandstones is essential in the exploration and production of hydrocarbon from the subsurface sedimentary strata as these properties strongly influence their reservoir qualities. Sandstones are deposited within sedimentary environments ranging from continental alluvial settings, to marginal coastal areas which are affected by riverine, waves and tidal processes, to deep submarine region. The primary properties of sandstones (texture, composition, sedimentary structures and stratigraphic heterogeneity) are largely determined by the source materials and by the environment of deposition (Reineck & Singh, 1980; Tucker, 1981; Selley, 2000). This study on the sedimentological (facies, grain size) and reservoir petrophysical properties (grain size, porosity, permeability) of sandstones will conducted on the reservoir rock of Miri Field. A diagenetic process in sandstone diagenesis occurs by three processes:

- Cementation
- Dissolution (leaching)
- Compaction

Cementation destroys pore space; grain leaching creates it. Compaction decreases porosity through grain rearrangement, plastic deformation, pressure solution, and fracturing. (Walton et al, 1986)

2.4 Lithology and Textures

Lithology is a function of transportation processes and the macroscopic nature of the mineral content, grain size, texture and color of rocks. The characters of reservoir rocks vary based on their sedimentary textures that are produced by depositional and diagenetic processes. The term texture has a broad meaning and refers to the interrelationships among the population (Krynine, 1948). Texture is also considered as a main factor controlling some petrophysical properties, such as porosity and permeability. The principal elements of texture are grain size and sorting and these elements are the commonly measured elements.

2.4.1 Grain Size

Grain size is the most fundamental physical property of sediment because grains are the particles which support the framework of a sediment. Sedimentary particles come in all sizes; it is convenient to be able to describe sediments as gravels, sands (of several grades), silt and clay. For many years, the size and distribution of the sand and gravel fractions were determined solely by sieve analyses. After the sieve analyses, the sample is separated into classes or groups. The classes are designated by logarithmic units or phi classes for statistical purposes (Table 1). In general, the grain size of sediments is a sign of the hydraulic energy of the environment. During the transport, movement and sedimentation, grains change their shape which is described by parameters of sphericity and roundness. (Wentworth, 1922)

Millimeters (mm)		Micrometers (µm)	Phi (φ)	Wentworth size class		Rock type
	4096		-12.0	Boulder	Gravel	Conglomerate/ Breccia
	256		-8.0	Cobble		
	64		-6.0	Pebble		
	4		-2.0	Granule		
	2.00		-1.0	Very coarse sand	Sand	Sandstone
	1.00		0.0	Coarse sand		
1/2	0.50	500	1.0	Medium sand		
1/4	0.25	250	2.0	Fine sand		
1/8	0.125	125	3.0	Very fine sand		
1/16	0.0625	63	4.0	Coarse silt	Silt	Siltstone
1/32	0.031	31	5.0	Medium silt		
1/64	0.0156	15.6	6.0	Fine silt		
1/128	0.0078	7.8	7.0	Very fine silt		
1/256	0.0039	3.9	8.0	Clay	Mud	Claystone
	0.00006	0.06	14.0			

Table 1: The Wentworth grade scale for sediments (Wentworth, 1922)

2.4.2 Influence of Sorting

Sorting and porosity strongly correlate in unconsolidated sandstones. Based on many sedimentology studies, shows that the better the sorting, the higher the porosity (Fraser, 1935; Rogers and Head, 1961; Pryor, 1973; Beard and Weyl, 1973). The initial porosities of wet, unconsolidated sands show a range of 44-28% porosity for well-sorted versus poorly sorted grains. The degree of dispersion of the grain population about the median or mean size is a very important to textural parameter. Dispersion is referred qualitatively as sorting but is express quantitavely as standard deviation, i.e. spread of the grain-size distribution. Sorting gives an indication of the depositional mechanism. Sediments deposited with high energy (strong current or waves) are generally poorly sorted; sediments which have been worked and reworked are much better sorted (Tucker, 1981)

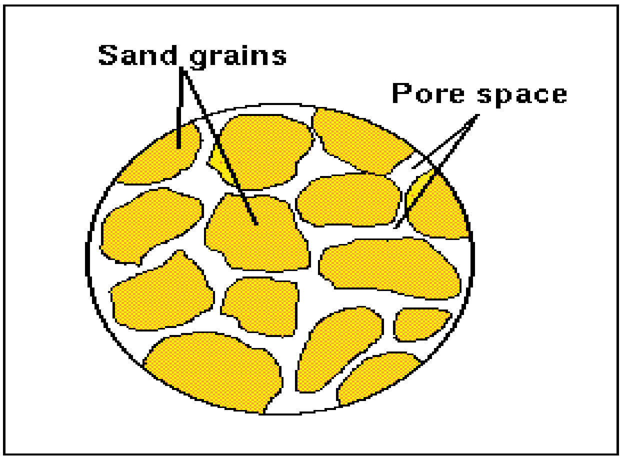

Figure 5: The distribution of sand grains showing the pore space

2.5 Porosity

Porosity is the ratio of pore space volume, which is not occupied by the solid constituents to the total volume (Schön, 1996; Selley, 2000). Porosity is a dimensionless quantity and expressed either as a decimal fraction or as a percentage.

Porosity = pore volume/total volume

= (total volume-solid volume)/total volume

Porosity describes the volume of the voids (pores, cracks, fissures, fractures, etc) in relation to the considered rock volume. (Serra, 1984)

Effective porosity is the amount of mutually interconnected pore spaces present in a rock which is available for free fluids and excludes all non-connected porosity including the space occupied by the clay-bound water. An important distinction must be made between the total porosity of a rock and its effective porosity. Since that the effective porosity is generally economically important, it is determined by most of the porosity measurements.

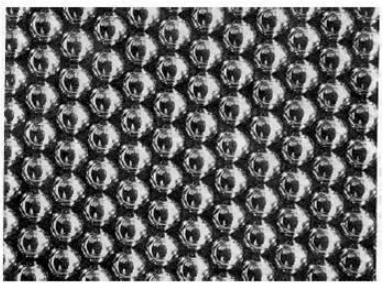

Figure 6: Perfect porosity

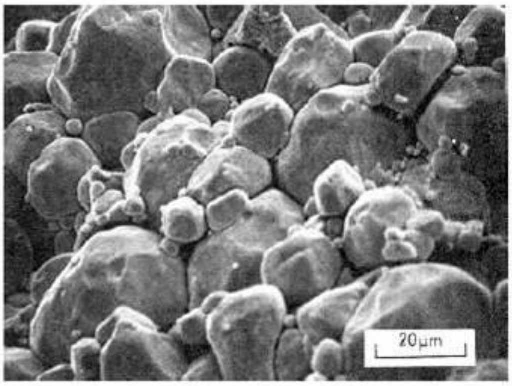

Figure 7: Porosity in real condition

2.6 Permeability

Rocks consist of grains of solid matter with varying shapes which are more less cemented, and may be surrounded by voids. The voids are able to contain fluids such as water or liquid or gaseous hydrocarbons and allow them to circulate. This ability of the rock to allow fluids to circulate is called permeability which is permeability is the ability of the rock to transmit fluid (Schon, 1996; Selley, 1998).

Pore throats are the smaller connecting spaces linking pores and providing the more significant restrictions to fluid flow. Permeability described the property of a porous rock regarding fluid flow through the pore space.

Permeability is related in a variable and complex way to porosity, pore size, arrangement of pores and pore throats, and grain size. Fine sediments such as clay exhibit low permeability compared to sand and gravel due to the lack of connection between the pore space and the small size of the pore throat. Grain packing also influences permeability.

CHAPTER 3.0: METHODOLOGY

3.1 Introduction

The ultimate goal of this chapter is to present all the methods that will be used in studying the heterogeneity and characteristics of reservoir. Therefore, this chapter is important in developing systematic approach that is applied during laboratory analysis. Several formulas and calculations, tools and hardware used are discussed in this chapter. The proposed methodology starts since early January until current analysis data.

3.2 Project Flow

In order to complete the study and achieved the objectives, the following steps must be considered;

I. Prepared data and samples for laboratory experiments.
II. Determining the grain size of the sandstone samples.
III. Determining the porosity of the sandstone (each layer) using the poroperm system equipment.
IV. Determining the thickness of each layer from the sandstone outcrop during the field trip.
V. Calculating the permeability and thin section for the samples.

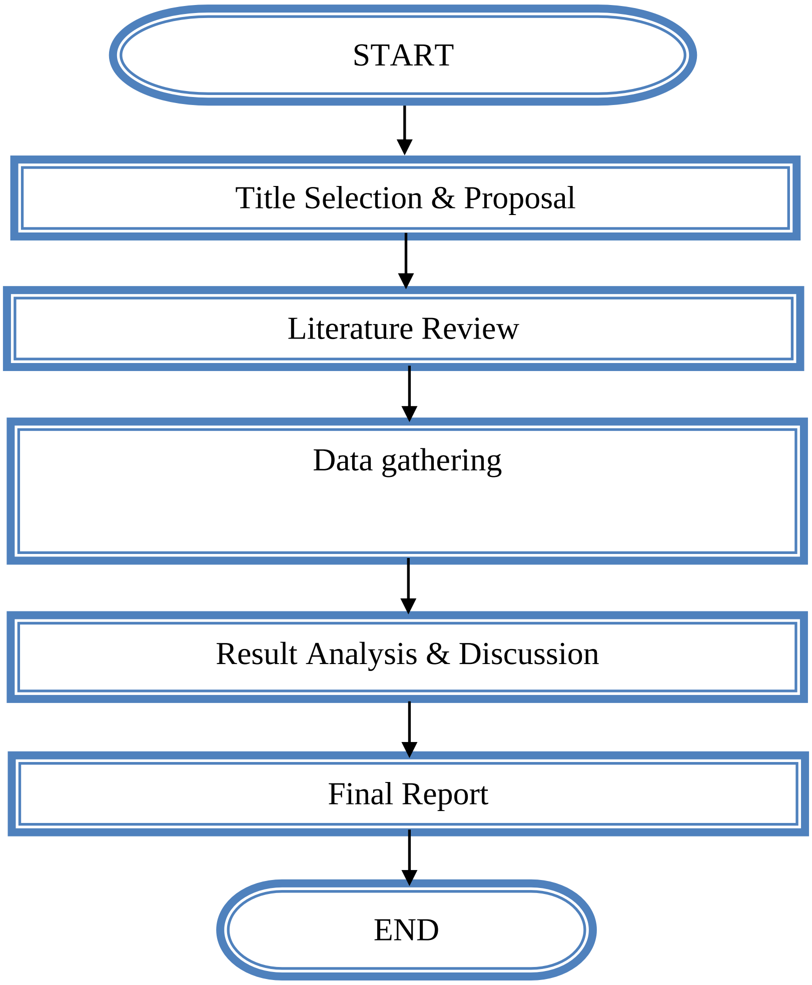

Figure 8: Project flow chart.

3.3 Field Work Analysis

Field work was conducted in January 2011 and work focuses on sedimentological description and manually logging outcrop with sampling of Hospital Road sandstone reservoir. Sedimentary rock that being exposed can be used in order to investigate various sedimentological and petrophysic properties.

3.3.1 Field Techniques

There are several aspects of sedimentary rocks to consider in the field, which should be recorded in as much detail as possible. These are;

- The lithology: composition, mineralogy of the sediment.
- The texture: the features and the arrangement of the grains in the sediment of which the most important aspect to examine in the field is the grain size.

- The sedimentary structures, present of bedding surfaces.
- The colour of the sediment
- The geometry and relationship of the beds or rock units and their lateral and vertical changes.

The various attributes of a sedimentary rock combine to define a facies, which is the product of a particular depositional environment. Facies identification and facies analysis are the next steps after the field data have been collected.

The best approach at outcrop is initially to survey rocks from a distance, noting the general relationship and any faults which are present. Some larger scale structures such as the geometry of sedimentary rock units, bed thickness variations, cross-bedding, and other related with study are best observed from a short distance to notice the way the rock are weathering out. These may be reflecting the lithologies and see what lithologies and lithofacies are exposed. For more details of the outcrop, it is best to note down and sketch to records all the information available on the outcrop. The main points to be covered in a field work entry:

- Lithology/mineralogy and texture: identify, describe and measure.
- Examine texture of the rock: grain size, shape and roundness, sorting, fabric and colour.
- Sedimentary structure: describe/measure, make sketches, and take photographs.
- Construct graphic log if needed, and sketches of lateral relationship.
- Identified facies present, note facies associations and repetitions.
- Make appropriate interpretations and notes for future work (e.g in the lab).

3.3.2 Rock Sampling

To further the studies, more than twenty (20) samples of thousand gram (1000gm) to two thousand gram (2000gm) were collected from the Hospital Road outcrop surface with hammer and a chisel during the field trips. The samples were chosen on rock type and lithofacies, most of the samples were sandstone that represented the Middle Miocene reservoir rocks of Miri formation. The stratigraphic locations of samples were marked on sedimentological graphic log. The samples were given numbers according to their place in the outcrop from the base to the top. A brief description of each specimen according to its lithology and lithofacies was performed during manual logging and sample collecting.

In the laboratory, the samples were trimmed in regular geometric core shape, in order to used for various petrophysical experiments. Unfortunately, some samples were destroyed during the process of transferring the rock from Miri to UTP through air and land transportation. A approximately 20 samples after choosing the best were used in this study.

3.4 Laboratory and Experiments analysis

20 samples chosen from different sandstone lithofacies were used to achieve the laboratory analysis, which involved petrophysical analysis.

3.4.1 HePorosimeter System (Porosity Test)

This lab experiment will be use to determine the porosity of core plug sample. The concept of HePorosimeter is the system allows for automatic Grain Volume and Pore Volume determination on rock samples including unconsolidated or irregular shape samples. Just enter the characteristic of your sample (ID, diameter, length and weight), click on the button Measure and the system work.

The measure is based on Boyle-Mariotte’s law theory. The process takes place in two stages: at stage one a known amount of helium gas is contained in a cell (pressure and volume accurately known). At stage two, this quantity of gas is shared with the matrix cup containing the sample. The new pressure is measured and the volume not accessible to gas (grain volume) is automatically calculated.

The system includes a console with necessary instrument and actuators connected to a matrix cup to accommodate 1” and 1”1/2 dia samples. An optional spare matrix cup is dedicated to full size samples (4” diameter). The console is controlled via user friendly interface on computer through serial connections (USB type). Calibration, Process operation, and report in Excel sheet are automatic through "macroCommand". (

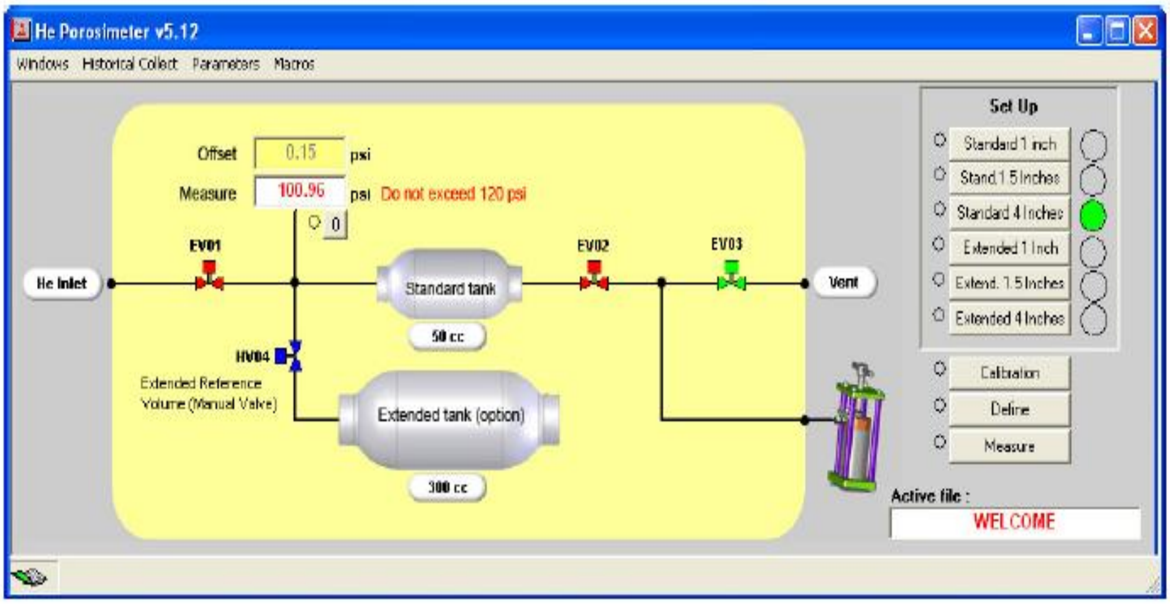

Figure 9: Sample Test

3.4.2 POROPERM System (Permeability Test)

POROPERM system is use to determine the permeability of core plug sample. The POROPERM instrument is a permeameter and porosimeter used to determine properties of plug sized core samples at ambient confining pressure. In addition to the direct properties measurement, the instrument offers reporting and calculation facilities thanks to its user-friendly windows operated software.

Direct measurements:

- Gas permeability (mD).
- Pore volume.
- Core length and diameter.

Calculated parameters:

- Klinkenberg slip factor "b".
- Klinkenberg corrected permeability.
- Inertial coefficients.

- Sample bulk volume.
- Sample porosity.
- Grain volume.
- Grain density (assuming sample is weighed).

The gas permeability determination is based on the unsteady state method (pressure falloff) whereas the pore volume is determined using the Boyles law technique. Length and diameter of the core sample are measured with digital caliper and subsequently bulk volumes are determined automatically.

Permeability is a property of a porous medium and is a measure of its ability to transmit fluids. The reciprocal of permeability represents the viscous resistivity that the porous medium offers to fluid flow when low flow rates prevail. In this system, the permeability calculation is based on Darcy's Low which uses the relationship between the permeability of a porous media and the potential gradient observed during the flow of a fluid through it this method is based on transient pressure technique for gases.

Figure 10: POROPERM System Equipment

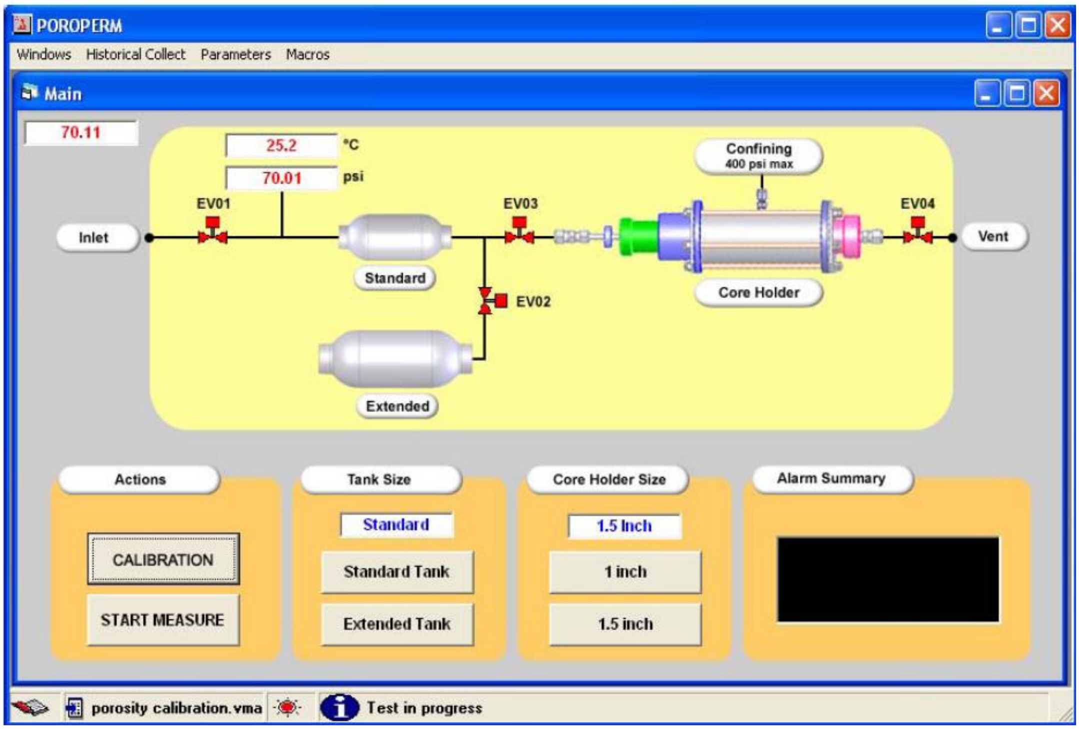

Figure 11: Operating Mode

CHAPTER 4.0: RESULT AND DISCUSSION

4.1 Introduction

This chapter present the result and discussion for the structure at Hospital Road. The data collected are presented starting from the sedimentological analysis during the fieldwork to the petrophysical analysis and sedimentology structures analysis from laboratory works.

4.2 Field Analysis

Field analysis or sedimentary work was conducted during the period of ten days. The result from the field analysis includes identified facies on each layer of the outcrop, measured thickness of the layer, lateral continuity of each layer, and manually sedimentary logging. Twenty to twenty five (20-25) samples of sandstone were taken between layers 1 to layer 16 for laboratory analysis.

4.2.1 Identification of Facies

Outcrops of thirty (30) metres lengths were studied considering there are different types of facies (Figure 12a and Figure 13a). The study of Hospital Road outcrop comprises several different facies of sand, shale, sand with horizontal bedded and thin shale laminated sand (Figure 12b and 13b). The sand dominates most of the layers followed by shale, then combination of sand-shale laminae. The physical properties are determined by combination of depositional. Most of the grains were transported water to the depositional site through mechanical and chemical weathering process where the sandstone having effects of compaction and chemical changes.

Facies one (1) is at the bottom part of the outcrop and identified as wavy bedded facies sand unit (Figure 14(1)). It consists of yellowish sandstone with wavy lamination. Along thirty meters (30m) of the selected outcrop, among the significant features are laminated bedding type which coarsening upwards. Facies two (2) is the thin bedded shale laminated sand which is characterized by coarse sand to silty laminations shale of eighty six centimetres (86cm) thickness and consist greyish-black mud stone colour.

Facies three (3) is the wavy parallel bedded sandstone (Figure 14 (3)) with thickness sixty three centimetres (63cm). It consists of small grain size, hard texture with lamination of reddish and yellowish sandstone. Facies four (4) is similar to facies two with thickness of fifteen centimetres (15cm) and coated greyish mud colour. Facies five (5) is wavy, discontinuous, parallel facies (Figure 14(5)) with orange reddish colour and average thickness of eighty two centimetres (82 cm). Facies six (6) is wavy, parallel horizontal bedded sandstone with thickness of hundred three centimetres (103cm). The most characteristic features of this facies are the lateral and discontinuous sandstone which occur on the upper part of Hospital road outcrop from facies seven until facies sixteen.

Facies 8 is the laminated mudstone with greyish-black colour. Average thickness is about seventy nine centimetres (79cm). This facies consists of mud stone and is generally non reservoir although minor porosity or permeability may occur in some of the sandier part. Facies 9 is a wavy, discontinuous, non parallel, thin bedded sandstone (Figure 14(9)) and similar to facies, 11, 13 and 15 with thickness range from ten to twenty centimetres (10-20 cm).

Overall, there are three main type of facies identified from Hospital Road outcrop wavy discontinuous parallel bedded (Layer 7), thin bedded wavy discontinuous non parallel bedded sandstone (Layer 11, 13, 15) and wavy discontinuous non parallel bedded sandstone (Layer 3).

Figure 12a: Upper part Hospital Road out crop layer by layer with facies

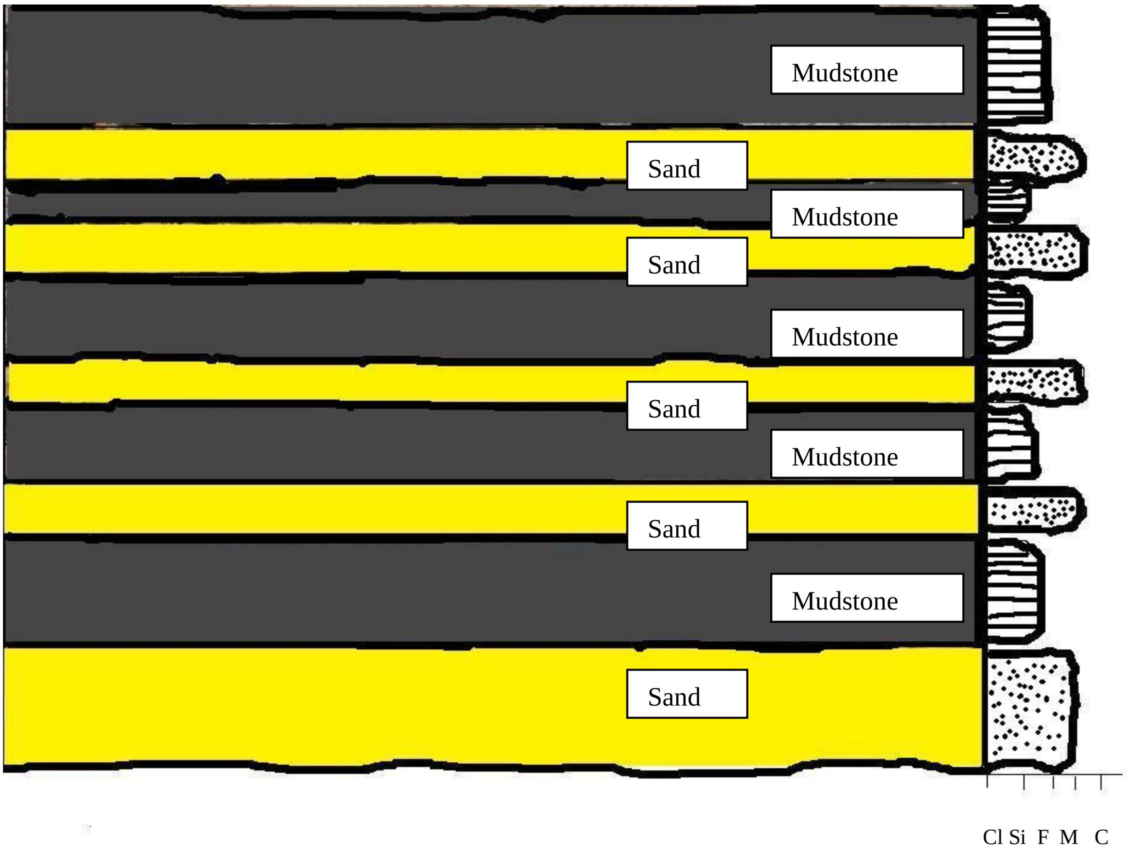

Figure 12b: Facies distribution of upper part Hospital Road outcrop after field study

Figure 13a: Lower part Hospital Road out crop layer by layer with facies

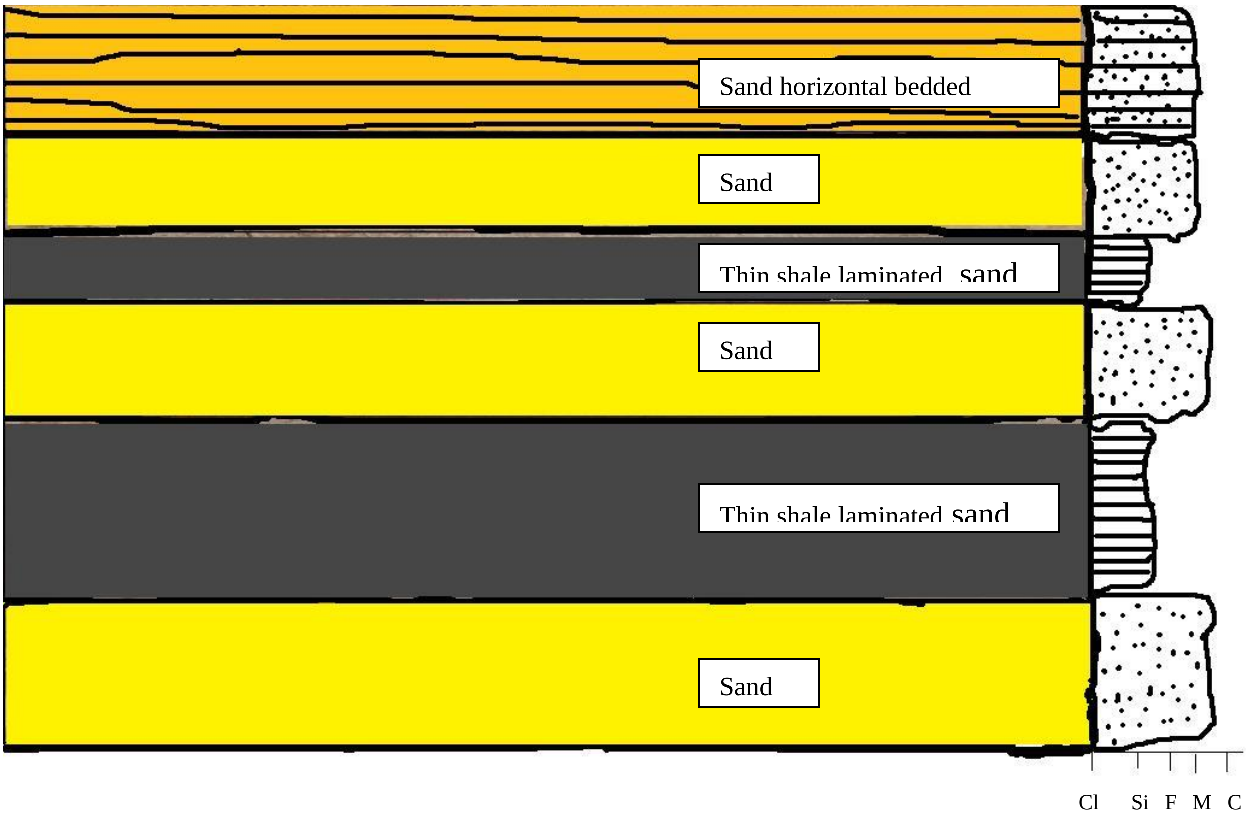

Figure 13b: Facies distribution of lower part Hospital Road outcrop after field study

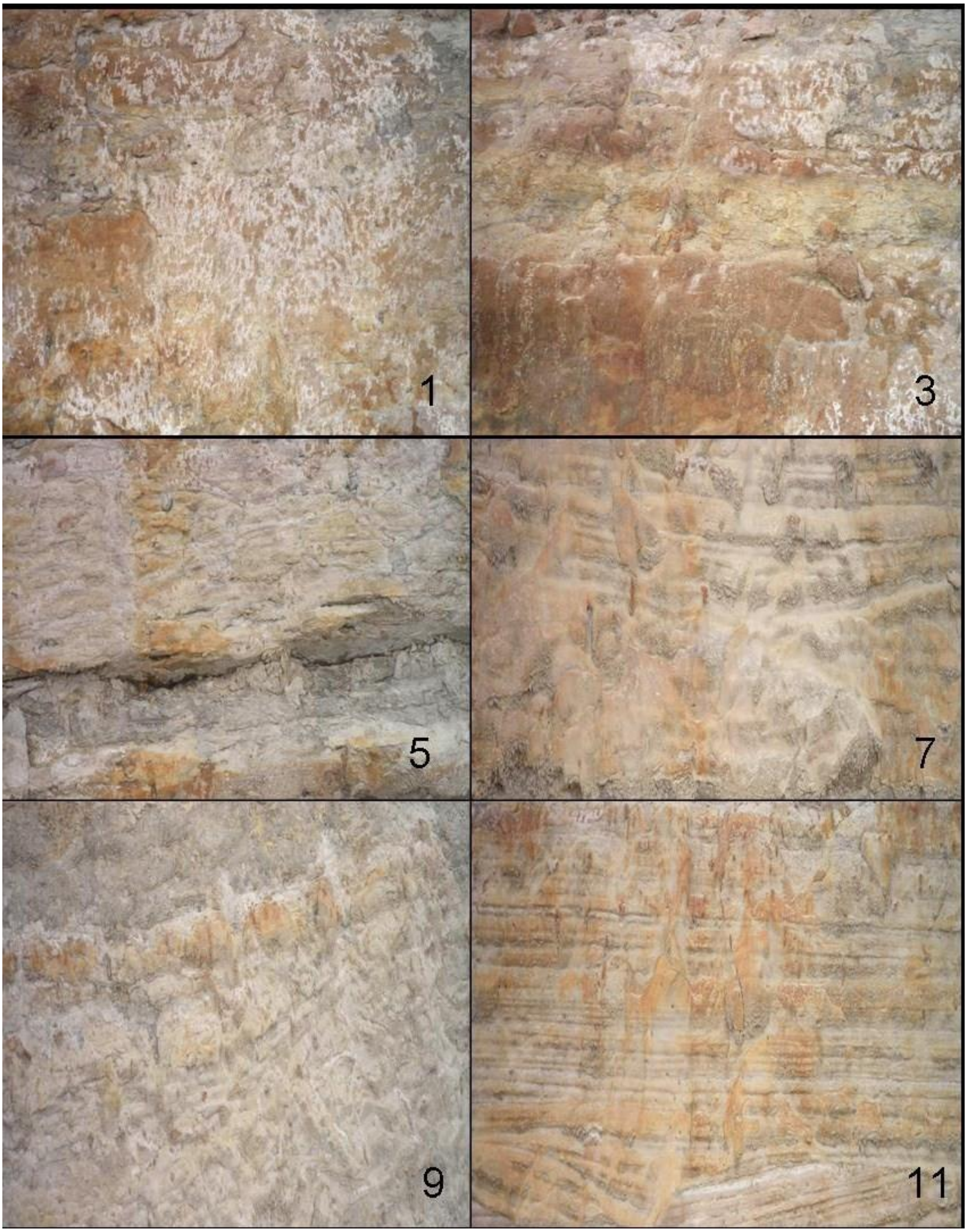

Figure 14: (1) wavy bedded facies; (3); wavy, parallel bedded facies; (5) wavy, discontinuous, non parallel facies; (7) wavy, discontinuous, parallel bedded facies; (9) thin bedded, wavy, discontinuous, non parallel facies; (11) thin bedded, wavy, discontinuous, non parallel facies

4.2.2 Thickness of facies

Different facies in the Hospital Road outcrop have different thickness. The thickest layer of sandstone on the outcrop is Layer six (103cm), followed by Layer one (90cm) and the lowest thickness is layer thirteen (14cm). The thickness of each layers are concluded in Table 1. The total of thickness for Hospital Road outcrop is nine hundred and twenty one centimetres (921cm). Then, layer with different facies was chosen to integrate information and details between them. Most of the rock sampling was taken from layer one, three, five, seven, nine and eleven to further studies on petrophysical properties which are porosity, grain size and permeability.

Layer	Facies description	Thickness(cm)	Lateral continuity (m)
1	Wavy bedded sand	90	More than 20 metres
2	Thin shale laminated sand	86	More than 20 metres
3	Wavy parallel bedded sand	63	More than 20 metres
4	Thin shale laminated sand	15	More than 20 metres
5	Wavy discontinuous non parallel sand	82	15-20
6	Wavy, parallel, horizontal bedded sand	103	More than 20 metres
7	wavy, discontinuous, parallel bedded sand	58	15-20
8	Mudstone	79	More than 20 metres
9	wavy, discontinuous, non parallel sand	18	15-20
10	Mudstone	62	More than 20 metres
11	Thin bedded, wavy, discontinuous, non parallel	19	15-20
12	Mudstone	71	More than 20 metres
13	Thin bedded sandstone	14	15-20
14	Mudstone	48	More than 20 metres
15	Thin bedded sandstone	16	15-20
16	Mudstone	97	More than 20 metres
	Total	921	15-20

Table 2: Description for thickness each facies and lateral continuity

4.3 Laboratory Analysis

Laboratory analysis consists of sedimentary structures analysis and petrophysical analysis (porosity and permeability).

4.3.1 Grain Size Analysis

Mode is a measure of the most frequent occurring particle classes. It is the highest point on the histogram and the point on maximum steepness on the cumulative arithmetic curve. Histogram in Figure 15 shows the entire distribution of facies frequently occurring particles classes. Since all the samples approximately 100% coarse to fine sand, each facies have two highest modes which are primary mode and secondary mode. Facies 7 has the highest primary mode of negative one (-1) phi and secondary highest mode of four (4) phi class. Apart from facies 7, facies 3 has the second highest primary mode negative one (-1) phi and secondary mode four (4) phi class.

Facies 1 is the third highest primary and secondary mode distribution among all the facies. This shows that facies 1 weight sample is very fine sand to coarse sand. Facies 5 which indicated by green bar in Figure 15 has primary mode of negative one phi class and secondary mode of 4 phi class. Table 3 summarize all the primary mode and secondary mode for each of the samples.

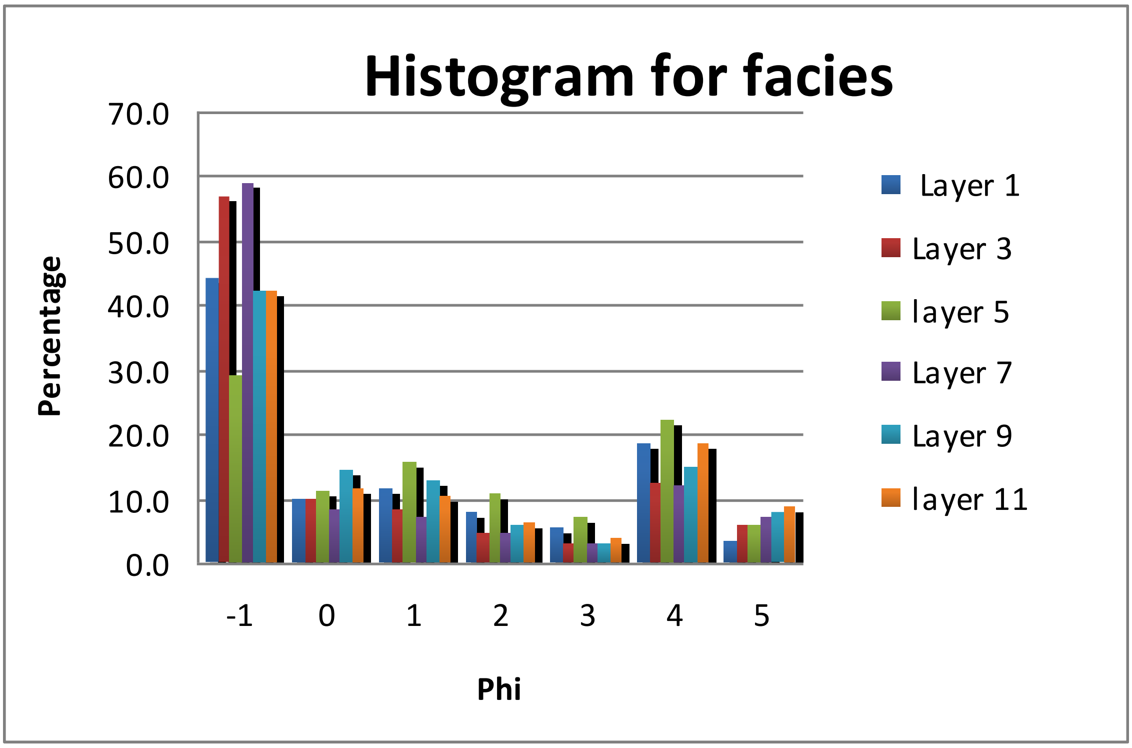

Figure 15: Histogram showing the entire Facies mode.

Layer	Facies description	Primary Mode, phi (ϕ)	Secondary mode (ϕ)
1	Wavy bedded sand	-1	4
3	Wavy parallel bedded sand	-1	4
5	Wavy discontinuous non parallel sand	-1	4
7	wavy, discontinuous, parallel sand	-1	4
9	wavy, discontinuous, non parallel sand	-1	4
11	thin bedded, wavy, discontinuous, non parallel	-1	4

Table 3: Distribution of primary and secondary mode for facies

4.3.1.1 Graphical Mean, M

Graphical mean is measured of the average particle size using cumulative arithmetic curve. Cumulative arithmetic curve is used to obtained data(s) required for calculation to determine the mean grain size of each facies. Folk & Ward, 1957 formula is utilized for this particular calculation. The classification of mean grain size is shown in Table 4. Table 5 shows variation of grain size for Hospital Road outcrop. Most of the facies classified as coarse sand with mean values ranges 0.1-1.0. Only facies 1 classified as medium sand with mean value 1.018. Formula for statistical parameters of grain size (Folk & Ward, 1957)

$$M = \frac{\varnothing16 + \varnothing50 + \varnothing84}{3}$$

Where; Ø16 = Phi value for 16% of cumulative weight percentage

Ø50 = Phi value for 50% of cumulative weight percentage

Ø84 = Phi class for 84% of cumulative weight percentage

Values from	**To**	**Equal**
- ∞	–1 ϕ	gravel
-1	0 ϕ	very coarse sand
+0	+1 ϕ	coarse sand
+1	+2 ϕ	medium sand
+2	+3 ϕ	fine sand
+3	+4 ϕ	very fine sand
+4	+8 ϕ	silt
+8	∞ □ϕ	clay

Table 4: Graphic mean (M) range and description (Folk & Ward, 1957)

Layer	Facies description	Graphic Mean (M)	Classification
1	Wavy bedded sand	1.018	medium sand
3	Wavy parallel bedded sand	0.153	coarse sand
5	Wavy discontinuous non parallel sand	0.939	coarse sand
7	wavy, discontinuous, parallel sand	0.103	coarse sand
9	wavy, discontinuous, non parallel sand	0.457	coarse sand
11	thin bedded, wavy, discontinuous, non parallel	0.553	coarse sand

Table 5: Interpretation for selected facies based on classification of grain size from Wentworth

4.3.1.2 Sorting

Sorting or standard deviation,D is measured to know the spread of the grain size distribution. It is one of the most useful parameters since it gives an indication of the effectiveness of the depositional medium in separating grains if different classes. From table 7, most of the selected facies mostly is poorly sorted to very poorly sorted with standard deviation value range 1.8 to 2.3.

$D = (\phi 84 - \phi 16) / 4 + (\phi 95 - \phi 5) / 6.6$

Values from	To	Equal
0.00	0.35 ϕ	very well sorted
0.35	0.50 ϕ	well sorted
0.50	0.71 ϕ	moderately well sorted
0.71	1.00 ϕ	moderately sorted
1.00	2.00 ϕ	poorly sorted
2.00	4.00 ϕ	very poorly sorted
4.00	∞ ϕ	extremely poorly sorted

Table 6: Standard deviation (D) range and description (Folk & Ward, 1957)

Layer	Facies description	Standard Deviation (D)	Classification
1	Wavy bedded sand	1.884	poorly sorted
3	Wavy parallel bedded sand	2.065	very poorly sorted
5	Wavy discontinuous non parallel sand	2.12	very poorly sorted
7	wavy, discontinuous, parallel sand	2.166	poorly sorted
9	wavy, discontinuous, non parallel sand	2.206	very poorly sorted
11	thin bedded, wavy, discontinuous, non parallel	2.256	very poorly sorted

Table 7: Layer by layer for selected facies and the interpretation based on Standard deviation (D)

4.3.1.3 Skewness, S

Skewness is a measure of the symmetry of the distribution and visually best seen from smoothed frequency curve. If the distribution has coarse sand, then the skew is positive. If the distribution is symmetrical, then there is no skew. Hospital out Road outcrop show most of the tested facies are positive skewed to strongly positive skewed.

$$S = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)}$$

Values from	**To**	**Mathematically:**	**Graphically Skewed to the:**
+1.00	+0.30	Strongly positive skewed	Very Negative phi values, coarse
+0.30	+0.10	Positive skewed	Negative phi values
+0.10	- 0.10	Near symmetrical	Symmetrical
- 0.10	- 0.30	Negative skewed	Positive phi values
- 0.30	- 1.00	Strongly negative skewed	Very Positive phi values, fine

Table 8: Skewness (S) range and description (Folk & Ward, 1957)

Layer	Facies description	Skewness(S)	Classification
1	Wavy bedded sand	0.351	strongly positive skewed and very negative phi value(coarse)
3	Wavy parallel bedded sand	0.801	strongly positive skewed but very negative phi values(coarse)
5	Wavy discontinuous non parallel sand	0.162	positive skewed but graphically negative phi values
7	wavy, discontinuous, parallel sand	0.758	strongly positive skewed, graphically skewed to the very negative phi values (coarse)
9	wavy, discontinuous, non parallel sand	0.535	positive skewed, graphically skewed to the negative phi values
11	thin bedded, wavy, discontinuous, non parallel	0.499	strongly positive skewed and graphically skewed to the negative phi values (coarse)

Table 9: Layer by layer for selected facies and the interpretation based on Skewness (S)

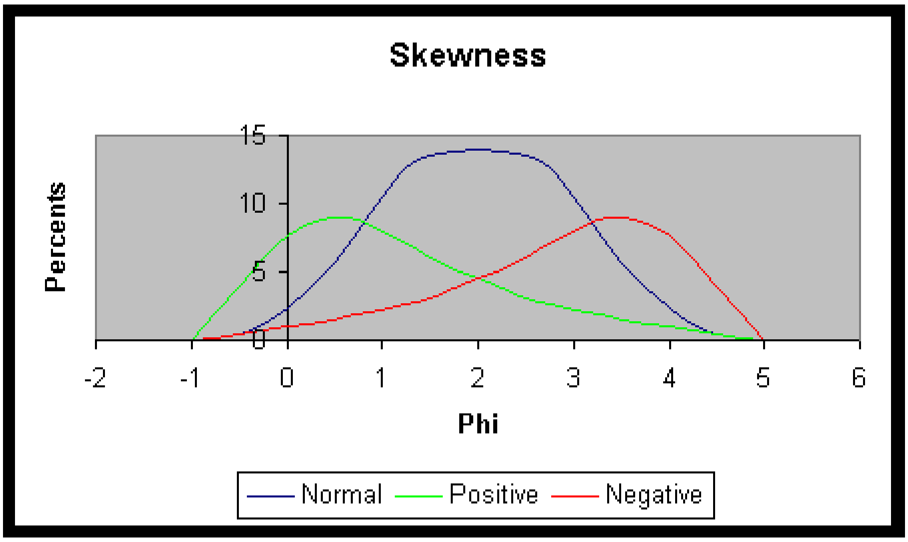

Figure 16: Skewness distribution normal, positive and negative. Hospital Road outcrop exhibit positive skewed. (From John R Anderson, Sand sieve analysis)

4.3.1.4 Graphic Kurtosis, K

Kurtosis, k is measures of the degree peakedness or departure from the "normal" frequency or cumulative curve. Leptokurtic curves are excessively peaked (center is better sorted than ends). Platykurtic curves are flat peaked which ends are better sorted than center. Mesokurtic curves are "normal" having a normal bell shaped curve.

Hospital Road outcrop have variation from mesokurtic, platykurtic and very platykurtic kurtosis. Facies 1, facies 7 and facies 9 exhibit platykurtic. Facies 5 and 11 exhibits a very platykurtic. On the other hand, facies 3 has equally flat-topped distributions where it is characterized as mesokurtic.

$$K = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

Values from	**To**	**Equal**
0.41	0.67	very platykurtic
0.67	0.90	platykurtic
0.90	1.11	mesokurtic
1.10	1.50	leptokurtic
1.50	3.00	very leptokurtic
3.00	∞	extremely leptokurtic

Table 10: Kurtosis (K) range and description (Folk & Ward, 1957)

Layer	Facies description	Kurtosis (K)	Classification
1	Wavy bedded sand	0.798	Platykurtic (ends are better sorted than center)
3	Wavy parallel bedded sand	1.037	Mesokurtic (a normal bell shaped curve)
5	Wavy discontinuous non parallel bedded sand	0.578	Very playkurtic (end are better sorted than center)
7	wavy, discontinuous, parallel bedded sand	0.907	Platykurtic (ends are better sorted than center)
9	wavy, discontinuous, non parallel sand	0.723	Platykurtic (ends are better sorted than center)
11	thin bedded, wavy, discontinuous, non parallel	0.573	Very playkurtic (end are better sorted than center)

Table 11: Layer by layer for selected facies and the interpretation based on Kurtosis (K)

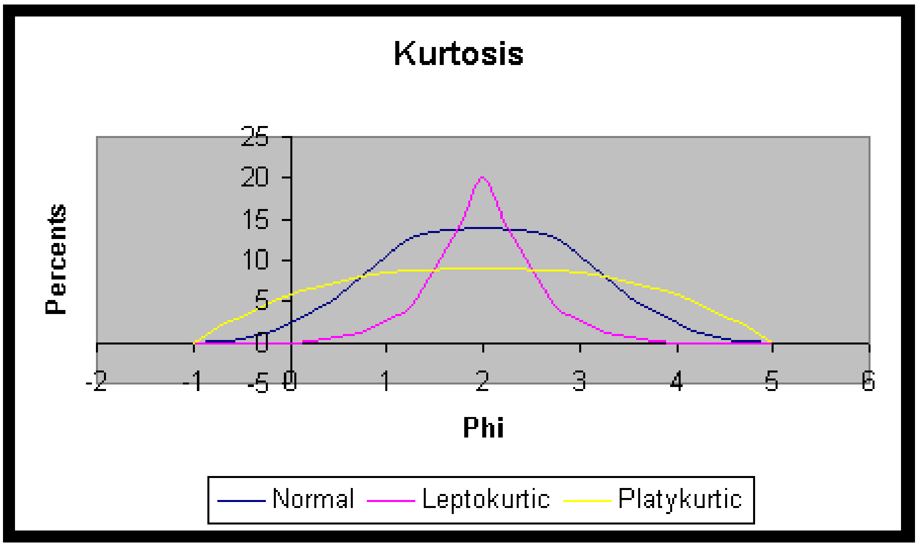

Figure 17: Kurtosis distribution normal, leptokurtic and platykurtic. Hospital Road outcrop exhibit platykurtic to very platykurtic (From John R Anderson, Sand sieve analysis)

All the values obtained for each parameter in gain size analysis are tabulated in table 20 at the end of this chapter.

4.4 Petrophysical Properties Analysis

Porosity and permeability was determined for facies 1, facies 3, facies 5, facies 7, facies 9 and facies 11. The average values, ranges and distribution properties of different facies summarized in Table 16

4.4.1 Porosity

Porosity was determined for layer that consist more sandstone which label as layer 1, 3, 5, 6, 7, 9, and 11. The average values, ranges and distribution properties of different facies shown in Table 12.

Porosity values for all sandstone lithofacies generally range from 15% to 28%. By comparison between facies porosity, layer 7 are dominated by the higher average porosity which is more than 25 % (Table 12). The highest porosity value belong with layer 11 (27.48%) and 9 (26.14%). Layer 5 and layer 7 shows average porosity of range 23% to 25.99% while layer 1 until layer 5 occurs to have the lowest value of porosity range from 15% until 23.99%.

Layer	Facies description	Thickness(cm)	Porosity (%)
1	Wavy bedded sand	90	15.23
3	Wavy parallel bedded sand	63	21.32
5	Wavy discontinuous non parallel bedded sand	82	23.32
7	wavy, discontinuous, parallel bedded sand	58	25.67
9	wavy, discontinuous, non parallel sand	18	26.14
11	thin bedded, wavy, discontinuous, non parallel	19	27.48

Table 12: Porosity values for selected facies

4.4.2 Permeability

Permeability (commonly symbolized as *k*) is a measure of the ability of a porous material (rock) to allow fluids to pass through it. Below are the results of the permeability analysis for the four (4) selected facies.

Facies 7 has a high value of permeability which is 63.41 mD. Facies 5 which has a wavy discontinuous parallel structure has a permeability of 52.73 mD. Facies 3 of wavy parallel bedded sand has a permeability value of 36.98 mD. Facies 1 has the lowest facies which is 6.52 mD.

Layer	Facies description	Thickness(cm)	Porosity (%)	Permeability,k (mD)
1	Wavy bedded sand	90	15.23	6.52
3	Wavy parallel bedded sand	63	21.32	36.98
5	Wavy discontinuous non parallel bedded sand	82	23.32	52.73
7	wavy, discontinuous, parallel bedded sand	58	25.67	63.41

Table 13: Permeability values for selected facies

4.5 Discussion

The petrophysics analysis has been performed for the selected layers and facies from the field work until laboratory work. The result of summarized both field and laboratory works shown in Table 14.

After all the field work and laboratory work had done, the discussion followed by:

- Facies 7 (Layer 7) has the highest porosity among the facies in Hospital Road which is 25.67%. It is the best facies in this outcrop because it contains quite a high porosity which means it can store more hydrocarbons. In terms of thickness, the thickness of this layer is about 72 cm and the continuity of the facies is about more than 30 meters.

- Facies 1 (Layer 1) has the lowest porosity among the facies that being tested from Hospital Road outcrop. Facies 1 thickness is 90 cm and the continuity is about more than 30 meters.

- Average porosity values for facies 3, 5, 9, and 11 with a range 21%-24% and 26%-28% respectively.

- From the grain size analysis, the selected facies chosen for testing shown most of the sand are poorly sorted to very poorly sort. This is because, due to different size in the sandstone itself (coarse sand-fine sand). This shows that, sandstone consist coarse to fine grain size. For the selected facies of the outcrop, most of the layer has coarse sand. This show the sandstones are heterogeneous characteristic. It is widely recognized that grain size and sorting variations are closely associated with facies changes.

- On the other hand, despite the different of the grain size and poorly sorted characteristics, the selected facies chosen for testing shown good average values of porosity and permeability due to the properties of sand where sand has a good porosity and permeability compared to other rock on the outcrop (laminated shale, shale-mudstone). Porosity in sandstones can be function of controlling factors as well as other petrophysical properties (grain size, permeability, others). This is because the properties for sandstone itself proved that it has good values in term of porosity and permeability due to depositional controls of grain size, sorting and grain shape and the diagenetic cementation and compaction.

- Hospital Road sandstone reservoir may have slightly small amount of mud and shale presence which might affect the capacity of the outcrop as mud is non porous rocks.

Facies	Mode (ϕ)		Mean (M)	Mean grain size	Standard deviation, (D)	Visual sorting	Skewness	Classification	Kurtosis	Classification	Porosity (%)	Permeability, (mD)
	Primary	Secondary										
1	-1	4	1.018	MS	1.884	PS	0.351	SPS	0.798	PK	15.23	6.52
3	-1	4	0.153	CS	2.065	VPS	0.801	SPS	1.037	MK	21.32	36.98
5	-1	4	0.939	CS	2.12	VPS	0.162	PS	0.578	VPK	23.32	52.73
7	-1	4	0.103	CS	2.166	PS	0.758	SPS	0.907	PK	25.67	63.41
9	-1	4	0.457	CS	2.206	VPS	0.535	PS	0.723	PK	26.14	-
11	-1	4	0.553	CS	2.256	VPS	0.499	SPS	0.573	VPK	27.48	-

Table 14: Summary and description on the petrophysic properties from laboratory analysis

MS = Medium Sand

CS = Coarse Sand

PS = Poorly sorted

VPS = Very Poorly sorted

SPS = Strongly positive skewed

PS = Positive skewed

PK = Platykurtic

MK= Mesokurtic

VPK = Very platykurtic

4.6 Uncertainties and Limitations

- Time

Due to the shortened period of research, most of the experiment work cannot be done on time, although more sample should be tested for each layer that been selected, only one sample can be tested which might reduce the accuracy of each layer. Some of experiment could not be done such as thin section.

- Experimental errors

The experimental error mostly occurs in sieving analysis. The time for shaking the samples in sieve should be increase to get better results. However, the time set only about 10-15 minutes.

Errors also occur during smashing the sandstone rocks, where the rock was not smashed properly and increase in weight of big particles than small particles during the sieving analysis. These errors lead to error in data analysis, interpretation and calculations

- Sample selections

To get good overview of result, sample selections should be made at various locations or section to determine the distributions of heterogeneities in the Jalan Hospital outcrop. If possible, the samples should be selected as many as possible at different locations of the outcrop.

The porosity value of the samples also might deviates from its supposed value, referring to the sedimentology properties as the tests of the sediments only cover small partial of the particular sample.

Some of the samples were broken due to the transferring the samples from Miri to UTP using air and land transportation, which might broken during the travels period.

CHAPTER 5.0: CONCLUSION AND RECOMMENDATION

1. In conclusion, considering facies and petrophysical analysis factors, after all, sandstones characteristics it is all about heterogeneity. A proper reservoir characterization is important to intergrate the effects on petrophysical and sedimentary facies of Miri sandstone. All rocks and formation reservoirs are build up thousand years ago due to changes of depositional environment and migration of sedimentology causing the heterogeneity in the sandstone reservoir. Intergrating facies behaviour and petrophysical properties will results in a good reservoir studies and possibility to be guidance in characterizing the heterogeneity in sandstone reservoir.

2. Facies 7 recorded the highest porosity (Φ :> 20%, k > 50 mD), good lateral continuity but very limited vertical continuity. Facies 7 recorded better poro-perm values trough existence of wavy, discontinuous, parallel sandstone without cross-bedded because they are generally coarse to fine average grain size and lack muddy laminations regardless it poorly sorted characteristics. Facies 7 sandstones of Miri Formation show high reservoir qualities (Φ :> 20%, k > 50 mD) with good lateral extent and uniform thickness.

3. Facies 3 and facies 5 sandstones shows moderate porosity and permeability (20%>Φ <25%, k >10 mD). Facies 3 shows wavy parallel bedded sand while facies 5 shows wavy discontinuous non parallel bedded sand.

4. Facies 1 sandstones are low in porosity (Φ :< 20%, k <10 mD) because of the poor sorting caused by infiltration of mudstone particles. Facies 1 exhibit wavy bedded sand with thickness of ninety centimetres (90cm) and generally coarse to fine grain size.

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APPENDIX I

FYP 2 GANTT CHART

Date **Activity**	W1	W2	W3	W4	W5	W6	W7	W8 16/03/2011	W9	W10	W11	W12	W13	W14	W15	W16- 17
Data Gathering																
Laboratory/ Experiments																
Experiments and Analysis																
Submitting Interim report																
Experiments and Analysis																
Data Analysis																
PRE-EDX																
Submitting final report																
Final presentation																FINAL EXAM

APPENDIX II

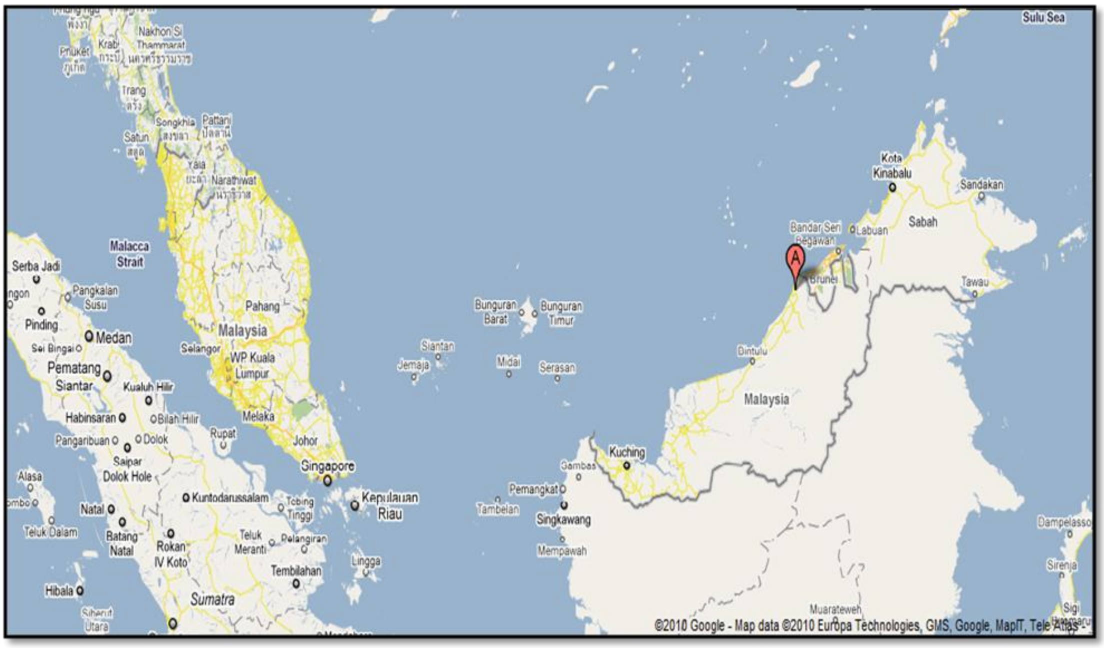

Figure 18: Location of Miri at northeastern Sarawak, northwestern side of Borneo Island is labeled by point A (Photo courtesy- Google Maps Europe technologies)

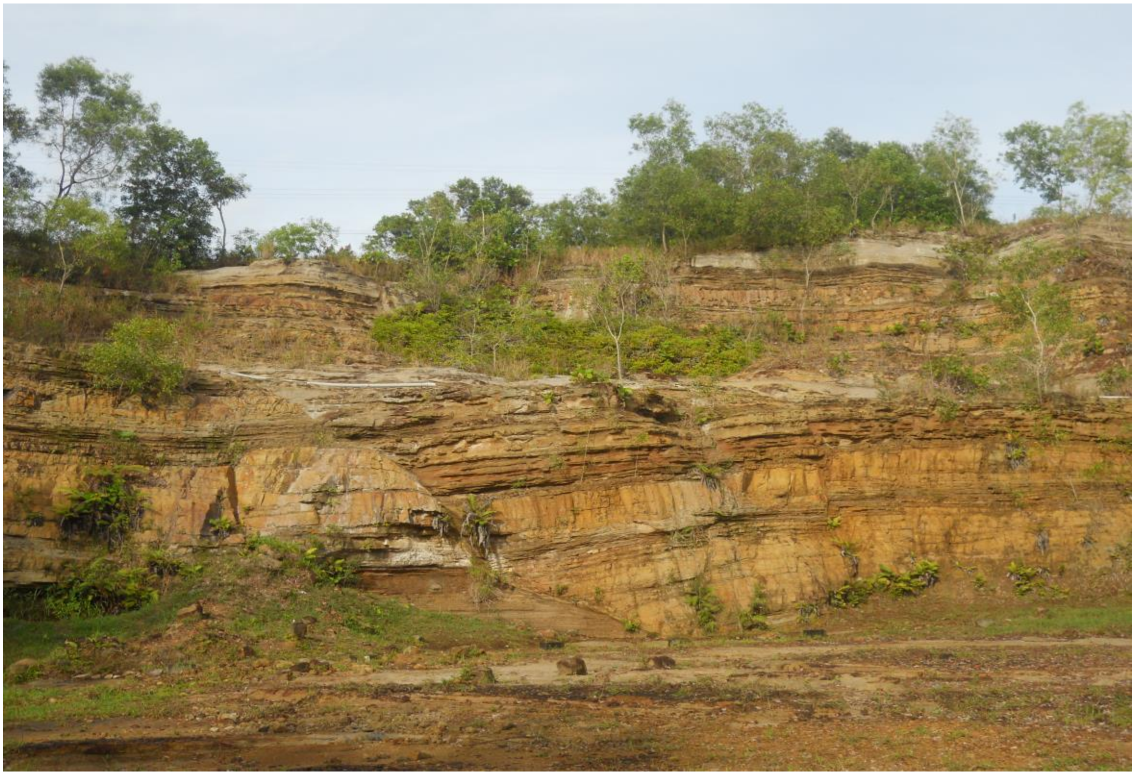

Figure 19: Picture above shows an outcrop of the Upper Miocene Miri Formation in the town of Miri deposited by the Paleo-Baram Delta. (Taken during field trip)

Figure 20: Poro-perm equipment provided in UTP laboratory

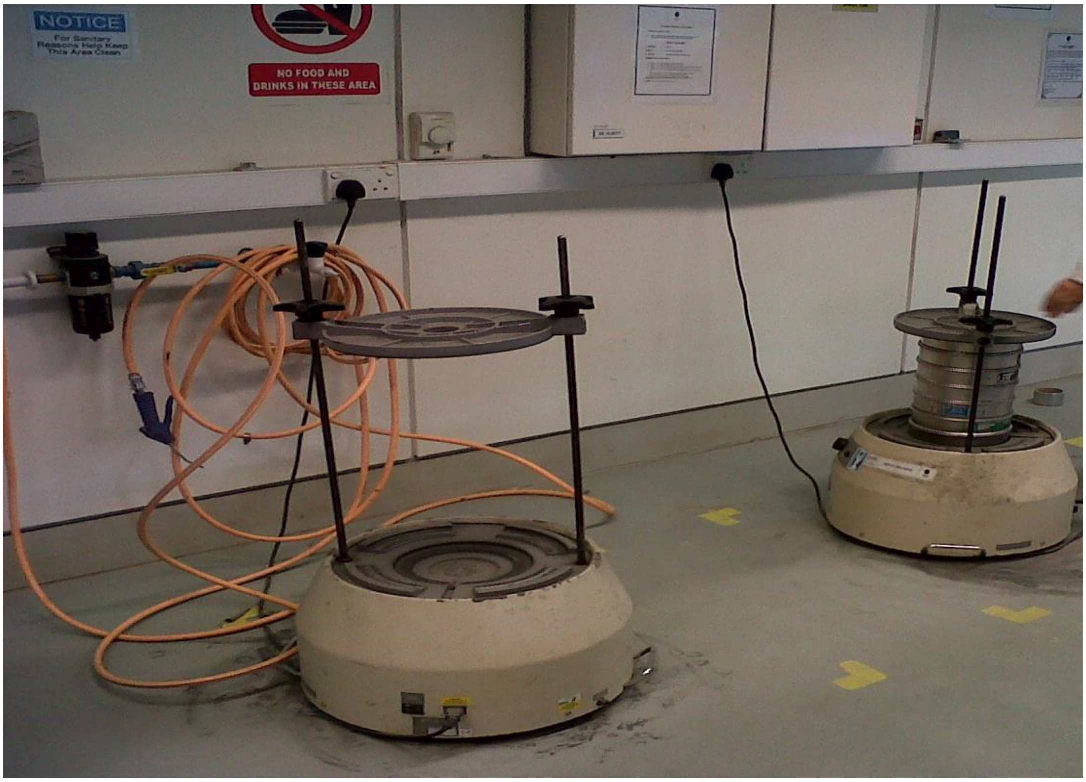

Figure 21: Sand sieve equipment provide in UTP laboratory

Figure 22: Facies 1 after grain size analysis

Figure 23: Facies 3 after grain size analysis

Figure 24: Facies 5 after grain size analysis

Figure 25: Facies 7 after grain size analysis

APPENDIX III – LABORATORY TEST

Universiti Teknologi Petronas
Geosciences and Petroleum Engineering Department
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Lab Experiment No. 1: Porosity Test

1. Objective:

To determine the porosity of core plug sample by using the **HePorosimeter** System.

2. Introduction

From the viewpoint of petroleum engineers, the two most important properties of a reservoir rock are porosity and permeability. Porosity is a measure of storage capacity of a reservoir. The porosity is calculated as ratio of the pore volume to the bulk volume of the core sample equation 1.

$$Porosity = \frac{Pore..Volume}{Bulk..Volume} = \frac{Bulk..volume - Grain..Volume}{Bulk..Volume} \quad (1)$$

Pore Volume: The pore volume is the volume in the sample that can be filled with a fluid. The advantages of determining this volume with helium is that invasion of the sample is rather easy (thank to the small size of the molecule and the low viscosity of the gas) and that the sample remains clean (not spoiled by oil or other liquid).

Bulk volume: For regular cylinders, the bulk volume is the cylinder volume of the core sample. The matrix cup can accommodate irregular core sample. In this case the bulk volume must be determined from mercury immersion for instance.

Grain volume: is the volume of solid of the sample. During the experiment, it is determined as the difference of a reference volume without and with the sample.

3. The Concept of HePorosimeter System:

This system allows for automatic Grain Volume and Pore Volume determination on rock samples including unconsolidated or irregular shape samples. Just enter the characteristic of your sample (ID, diameter, length and weight), click on the button Measure and the system work.

The measure is based on Boyle-Mariotte's law theory. The process takes place in two stages: at stage one a known amount of helium gas is contained in a cell (pressure and volume accurately known). At stage two, this quantity of gas is shared with the matrix cup containing the sample. The new pressure is measured and the volume not accessible to gas (grain volume) is automatically calculated.

The system includes a console with necessary instrument and actuators connected to a matrix cup to accommodate 1" and 1"1/2 dia samples. An optional spare matrix cup is dedicated to full size samples (4" diameter). The console is controlled via user friendly interface on computer through serial connections (USB type). Calibration, Process operation, and report in Excel sheet are automatic through "macroCommand"

Console: The console is the box that includes plumbing, valves, manometer and pressure transducer.

Matrix cup: The matrix cup is connected to the console. It accommodates core sample and calibrated billets.

4. Boyle-Mariotte's Law

The Boyle-Mariotte's Law is used to determine grain and pores volume from the expansion of a known mass of helium into a matrix cup. The following equations are used to calculate the porosity of core sample.

$$pore.volume = \frac{P.ref}{P.\exp} * V.ref - Vdead \tag{2}$$

$$grain.volume = (V.matrix + V.ref) - \frac{P.ref}{P.\exp} * V.ref \tag{3}$$

$$bulk.volume = (\pi D^2 / 4) * L \tag{4}$$

Where

P.ref = Reference Pressure (initial pressure)
P.exp = Expanded Pressure (final pressure)
V.ref = Reference Volume (initial volume)
V.exp = Expanded Volume (final volume)
V.dead = gas volume gathers surrounding the core
V.matrix = volume of the matrix cup,

P.ref and P.exp are measured with the HePorosimeter. V.ref, V.matrix and V.dead are determined using the calibration method provided with the machine.

5. Step by Step Procedure to Start Sample Test

Most of time, the daily work will be to simply click on Measure. To reach this status, you need at first to run four stages. You have to differentiate each class for calibration and for Measure.

1. Setup: Setup allows for selecting the suitable class to operate. In the Setup panel, click on the button relative to the reference volume to use (standard or extended) and your sample series (1", 1"½, 4"). After a few seconds, a green light is displayed beside your selection.

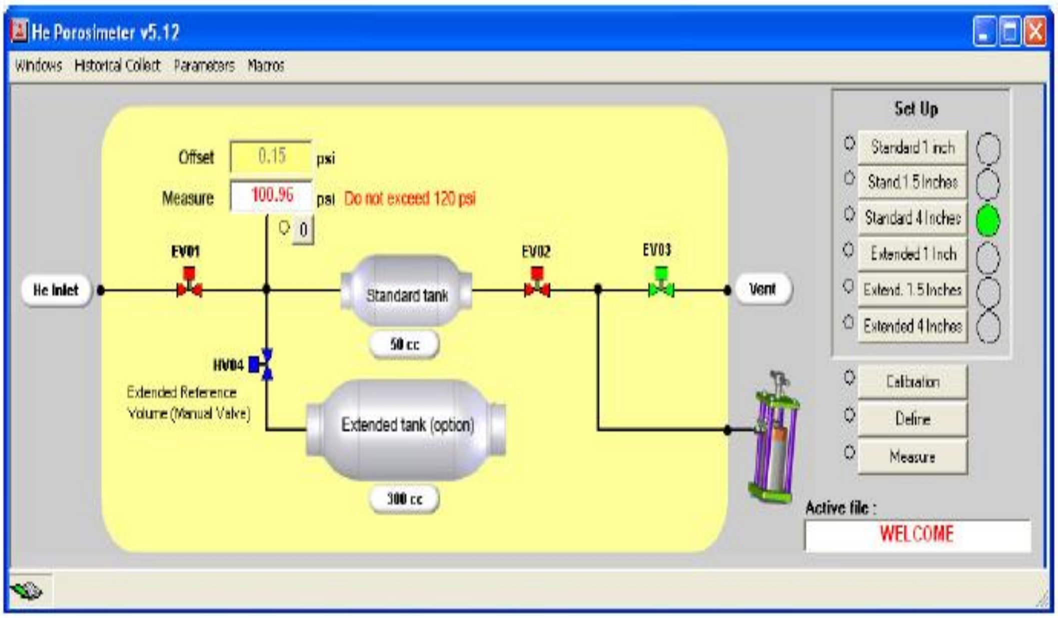
2. Define: Define allows the operator to define the working report file with a name of its own.

1. Start the definition by clicking on the button "definition", wait the loading of the macro until a dialog box appears, and follow the instructions.
2. Rename the new file to allow you entering the requested information in the yellow column at Report tab.
3. Key in the core ID, core diameter, length, and the weight and then close the renamed file.
4. Open the matrix cup and load the core sample.
5. Load one or several billets to fill in the empty place in the matrix and then close tight the matrix cup.

3. Measure:

Start the measurement by clicking on the button "measurement", wait until the next dialog box appear.

1. So this next dialog box asks you to close HV04, click Ok.
2. The second dialog box asks to confirm to start proceed, clicking YES.
3. The third dialog box requests to write the billets that you loaded with the core write the numbers of these billets and click OK.
4. When your sample is measured, the dialog box asks you to proceed to a next sample click "No".
5. A new dialog asks to fill the number of the sample to proceed, and then enter 0 to quit the measure mode.
6. At this time, you can read all the results for this sample from the file.



Computer interface

Results and Discussions

UNIVERSITI TEKNOLOGI PETRONAS	Universiti Teknologi Petronas Geosciences and Petroleum Engineering Department Bandar Seri Iskandar. 31750 Tronoh			
Experiment no 1: Porosity Determination			**Data:**	
Key in parameters				
		Sample 1	Sample 2	Sample 3
1	Core plug sample ID			
2	Core plug sample diameter, mm			
3	Core plug sample length, mm			
4	Core plug sample weight, g			
5	Filled up billets numbers			
The results for the porosity				
6	Bulk volume cc			
7	Grain volume cc			
8	Pore volume cc			
9	Grain density g/cc			
10	Effective core porosity %			

Discussions:

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Conclusions:

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APPENDIX IV – LABORATORY TEST (2)

Universiti Teknologi Petronas
Geosciences and Petroleum Engineering Department
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Lab Experiment No. 2: Permeability Test

1. Objective:

To determine the permeability of core plug sample by using the *PoroPerm* System **Figure 1**.

PoroPerm system

2. Introduction

The POROPERM instrument is a permeameter and porosimeter used to determine properties of plug sized core samples at ambient confining pressure. In addition to the direct properties measurement, the instrument offers reporting and calculation facilities thanks to its user-friendly windows operated software.

<u>*Direct measurements:*</u>

- Gas permeability (mD).
- Pore volume.

- Core length and diameter.

Calculated parameters:

- Klinkenberg slip factor “b”.
- Klinkenberg corrected permeability.
- Inertial coefficients.
- Sample bulk volume.
- Sample porosity.
- Grain volume.
- Grain density (assuming sample is weighed).

The gas permeability determination is based on the unsteady state method (pressure falloff) whereas the pore volume is determined using the Boyles law technique. Length and diameter of the core sample are measured with digital caliper and subsequently bulk volume are determined automatically.

3 Permeability Determination

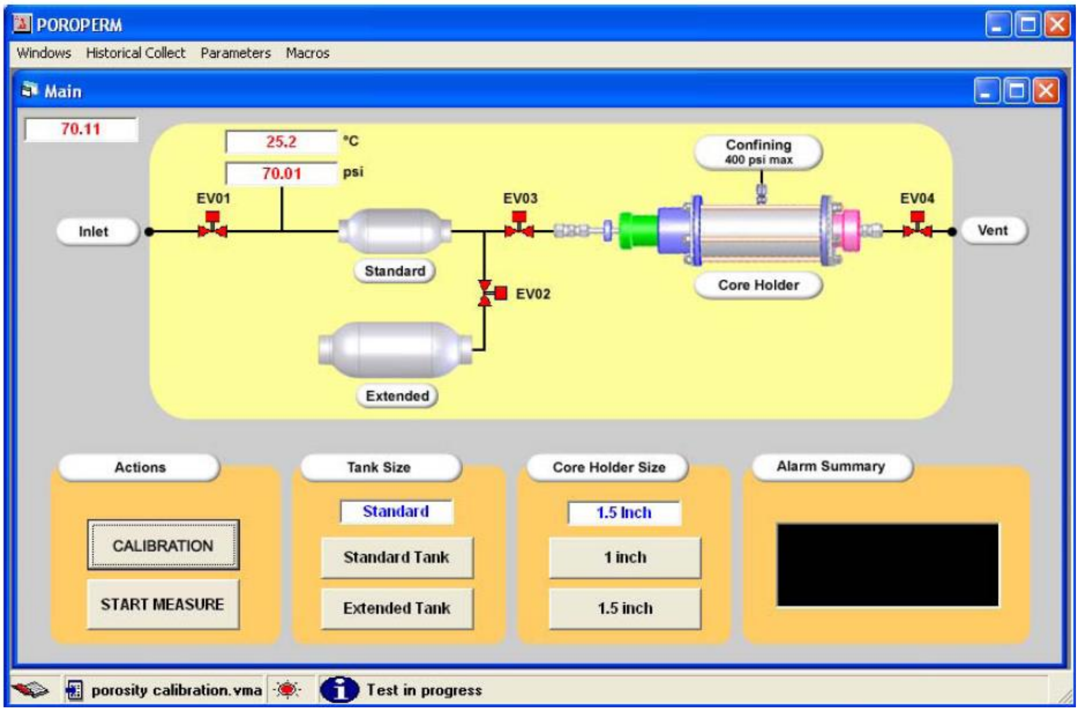
Permeability is a property of a porous medium and is a measure of its ability to transmit fluids. The reciprocal of permeability represents the viscous resistivity that the porous medium offers to fluid flow when low flow rates prevail. In this system, the permeability calculation is based on Darcy's Low which uses the relationship between the permeability of a porous media and the potential gradient observed during the flow of a fluid through it this method is based on transient pressure technique for gases.

4. Step by Step Procedure to Start Calibration

6. Select your tank size by clicking on one of the buttons “Standard tank” or “Extended tank” on the supervision.
7. Select your coreholder size by clicking on one of the buttons “1 inch” or “1.5 inch” on the supervision according to the coreholder installed on the PoroPerm.
8. Start the calibration by clicking on the button “Calibration”, wait the loading of the macro until a dialog box appears, and follow the instructions.

This first dialog box ask you if you want to proceed to the sample 1: click “Yes”

7. Load the first plug of calibration which is the standard plug number 2.
8. Then a second dialog box the number of the drilled plug loaded in the coreholder enters: 2. then click Ok.
9. Now the PoroPerm proceed to the measure of this standard plug, so wait until the next dialog box appear.
10. So this next dialog box asks you if you want to proceed to the sample 2: click “Yes”, then load the standard plug number 3.
11. Do the same operation until you have measured the standard plug 2 to 10.
12. When all standard plugs are measured, when the dialog box ask you to proceed to a next sample click “No”.
13. A new dialog ask to fill the number of the plug to proceed, then enter 0 to quit the calibration mode



Operating mode

5. Step by Step Procedure to Start Sample Test

After a new calibration, all your data of calibration are recording in the excel file c:\applilab\project\poroperm\excel file\Template.xls. However, before starting a new series of measures, in the directory C:\applilab\project\poroperm\excel file\, copy the file Template.xls, paste it in the same directory and rename it. Then open your new file and follow these instructions:

1. Select the "Info" sheet.
2. Fill the fields Sample ID, Diameter, Length, Weight, Atmospheric Pressure and Depth for each sample you want to measure (one sample per line).
3. Choose the measures you want to do on each sample: Porosity, Permeability or both.
4. In case for a sample you only want to perform a Permeability measure you have to fill the field Pore Volume.
5. Save and close your file.
6. Then start the measure sequence by clicking on the button "Start measure".
7. Load the coreholder with the first sample to measure.
8. Wait the first dialog box appears which is asking you fill the name of your measure file, fill it and click Ok.
9. A second dialog box appears if you want to proceed to sample 1 click "Yes" and wait the end of measure.
10. At the end of the first measure a new dialog box will ask you to proceed to the next sample, so change your sample and click "Yes".
11. Do the same operations until you have measured all you sample.
12. When all your samples are measured, when the dialog box ask you to proceed to a next sample click "No".

13. A new dialog asks to fill the number of the sample to proceed, and then enter 0 to quit the measure mode.

Results and Discussion

UNIVERSITI TEKNOLOGI PETRONAS	Universiti Teknologi Petronas Geosciences and Petroleum Engineering Department Bandar Seri Iskandar. 31750 Tronoh			
Experiment no 2: Permeability Determination			**Data:**	
Key in parameters				
		Sample 1	Sample 2	Sample 3
1	Core plug sample ID			
2	Core plug sample diameter, mm			
3	Core plug sample length, mm			
4	Core plug sample weight, g			
5	Room temperature, C^o			
6	Confining pressure, Psi			
7	Atmospheric pressure, Psi			
8	Pore volume cc			
9	Bulk volume cc			
13	Air permeability md			

Discussions:

Conclusions:

APPENDIX VI