FACIES AND RESERVOIR CHARACTERISTICS OF CROSS-BEDDED AND PLANE-BEDDED SANDSTONE

By:

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PROGRESS REPORT

SUPERVISOR: Assoc. Prof. Dr. Abdul Hadi B. Abd Rahman

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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BACHELOR OF ENGINEERING (Hons)

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Approved by,

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(AP Dr. Abdul Hadi B. Abd Rahman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2012

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.

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(AIMAN AJMAL BIN KAMARUZAMAN)

ABSTRACT

Most of Malaysia reservoirs are coming from sandstone formation. Sandstone is a sedimentary rock. Sedimentary rocks are formed when loose are laid down and with time, these sediment might located thousand of thick feet. Due to compression of accumulate overlying sediments, with the increase of heat and pressure, the physical and chemical are altered to form sedimentary rock. One of the features of sedimentary rock is stratification. The stratification can be categorized into two departments, planar stratification and cross stratification. There are terms that always be used to explain the stratification. For example like stratum (plural is called strata) which is defined as individual layer in a sediment or sedimentary rock that is produced by deposition. The terms like lamina (laminae) and bed (beds) can be defined as a stratum that is less than one centimetre thick and greater than one centimetre thick respectively. Correspondingly, stratification is termed either lamination or bedding.

Cross-bedded and plane-bedded of sandstone are the sedimentary structures to be study in this research. The area of study is included the facies analysis and reservoir characteristics. A facies is defined by a particular set of sediment attributes like lithology, texture, suite of sedimentary structures, fossil content and others. In the field and during the early stage of study, facies should be referred to only the descriptive sense and the interpretations in term of process and environment come later. The specifications of reservoir rock are the capacity to store hydrocarbon and the ability to allow hydrocarbon to flow through a conduit. The properties that affected the capacity and flows are porosity, permeability, fluid saturation and capillary pressure.

The fieldtrip and laboratory examinations are several of activities had been proposed to be implementing in the project. Fieldtrip to the area of study which is south region of Bintulu is believed can help the author to collect samples from there and exposed to the area of study. Laboratory examinations are important in analysing samples and hence solve the questions of uncertainty issues during the early fieldtrip. The uncertainty issues are like porosity, permeability, grain size and others. The laboratory equipments that suggested to use are Rotap shaker for sieving, SME for observing the unseen particles, and POROPERM for determining porosity and permeability.

Keyword: Cross-bedded, Plane-bedded, Sandstone, Facies, Reservoir characteristics, Fieldtrip, Laboratory works.

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Firstly, I would like to thank my FYP Supervisor, **Assoc. Prof. Dr. Abdul Hadi B. Abd Rahman**. He is the Head of Department (HOD) and lecturer in Geosciences Department. He is specialised in Clastic Sedimentology, Facies Analysis, and Well Log Analysis. He always gives me support and guides me in finishing this project. From time to time, I kept seeing him, to ask his advices and opinions regarding this project. His wisdom had helped me a lots to complete the project.

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ABBREVIATION

FYP **:** Final Year Project

HCS **:** Hummocky Cross-stratification

SEM **:** Scanning Electron Microscope

UTP **:** Universiti Teknologi PETRONAS

INTRODUCTION

1.1 Background Study

In sedimentary rock the obvious features to be known is stratification. The definition of stratification is layering by sediment deposition. Stratification is termed either lamination or bedding. Stratification is one of the most visible and striking features of sedimentary rocks but some stratification is subtle and requires care in observation. In particular, lamination is invincible on the fresh surfaces of sedimentary rocks but become apparent upon slight to moderate weathering of the surface. Likewise, lamination in well-sorted non consolidated sands does not show up well on a cut and trimmed surface through deposit until drying by the wind has etched some laminae more than others. There are two kind of physical stratification features: planar stratification and cross stratification.

Figure 1: *Planar Stratification*

Figure 2: *Cross Stratification*

Facies and reservoir characteristics are to be determined by the facies description and laboratory examinations. During the fieldtrip, there are 6 aspects of sedimentary rocks to be considered and recorded as much detail as possible. The aspects are lithology, texture, sedimentary structures, colour of the sediments, geometry, and last but not least the fossil content. Laboratory examination is aimed to find out several properties of rock such as grain size, type of sorting, porosity, and permeability.

1.2 Problem Statement

1.2.1 Problem Identification

Interpretation of samples from south region of Bintulu is made based on facies description and reservoir characteristics. The challenge is to find the best sample that produce good result from experimental works. Facies description is significant in supporting the experimental works result. The correlation between the facies description and experimental works can produce robust result.

1.2.2 Significant of Project

The restrictions that occur during the process of gathering the data (grain size, sorting and grain fabric) and measuring the porosity and permeability of the samples from the south region of Bintulu planned to be solve by implementing the propose methods. The success in solving the restrictions can resulted robust and relevant outcomes. In coming outcomes could help the geologists and engineers to understand the facies and reservoir characteristics of cross-bedded and plane-bedded sandstone at south region of Bintulu. Besides it is hoping useful for the exploration and production operation in future.

1.3 Objectives

The objectives of my project are:-

1. To identify the planar and cross stratification in Nyalau formation especially at the south region of Bintulu.
2. To study the sediment facies of outcrops based on the observation of bedding, sedimentary structures, sediment texture and fabric, sediment composition and colour and other.
3. To find out the best sample among the clean sandstone samples from the south region of Bintulu that contain high porosity and permeability and well sorted.

1.4 Scope of Study

The scope of study is about the investigation of facies and reservoir characteristics of cross-bedded and plane-bedded sandstone. The understanding of sedimentology or facies is important in helping us to run the research. The criteria like thickness and sandstone texture (size, grain fabric, sorting, petrography, porosity, and permeability) are the data that the author needs to gather and analyse before come up with the result.

The study of the samples from the sites at Nyalau formation especially at the south region of Bintulu, Sarawak is the requirement in this project. During visiting the site, the outcrop physical details (facies description) and thickness of outcrop will be recorded. The samples will be sending to the laboratory for extensive analysis. Furthermore, this project is concentrated on the samples from cross-bedded and plane-bedded sandstone.

During the fieldtrip, the author has to describe the outcrops physical features and collect sandstone samples from different lamination or bedded. While in laboratory, the petrophysical testing and measurements are to be held. These include sieving analysis, porosity and permeability analysis (POROPERM or Mercury Pressure Porosimeter) and others. Sieve Shaker is used to determine the grain size distribution of samples sediments. While the equipment like Pascal 140 and Pascal 240 (Mercury Pressure Porosimeter) are working out to measure the samples porosity and permeability.

1.4.1 The Nyalau Formation, Bintulu (Sarawak)

The Nyalau formation (Middle Miocene) of Bintulu area, Sarawak occurred as offshore-subtidal estuarine sandstones, sandy shales, and shale with dispersed lignite bands and marls, (2) silty sandstone interval partly calcareous and grading into sandy-limestone, (3) biban sandstone member with Oligocene-Miocene age which consists of fine- to medium grained sandstones and siltstones with calcareous nodules and (4) Kakus member of this formation with Lower-Middle Miocene age which consists of massive sandstone intervals, laminated clays, and brackish-shales and lignites (Liechti & Haile, 1960).

1.5 The Relevancy of the Project

Sandstones frequently form major aquifers and petroleum reservoirs, with predictable geometry and reservoirs performance compared to carbonates. This is because sandstones are more uniform in their facies characteristics and petrophysical properties. Many oil fields produce from fluvial sand where cross bedding lamination is one of the most common types of small-scale heterogeneity (Wahaibi, Muggeridge, & Grattoni, 2005). The study of sedimentology and reservoir characteristic of cross bedded and plane bedded sandstone may be can improve the understanding toward this formation and contribute valuable result for future exploration and production operation.

1.6 Feasibility of Project within Scope and the Time Frame

The author strongly believes that based on scope of study and the time frame set for the research, all the objectives will be achieved in providing scientific findings and observations to give the best outcomes from the analysis of cross-bedded and plane-bedded sandstones of the Nyalau formation particularly the south region of Bintulu. The materials will be taken on FYP 2 period and the equipments are ready to be conduct for the experiments. However time constraint can still be an issue due to other academic commitments.

LITERATURE REVIEW

2.1 Introduction

The objective of the research is to improve the understanding of relationship between geometry and sedimentary structure in interpreting sedimentary facies of sandstones in Nyalau formation (South region of Bintulu). On the other hand, the analysis of cross-stratification of sandstones in the formation can provide an unequalled basis for making paleohydraulic interpretations of ancient depositional environments. The aspects that can be inferred from the forms of cross-stratification include the relative flow strength, the direction of the current, and the type of current like upper or lower flow regime. The introduction of facies description can guide our interpretation of the reservoir at Nyalau formation.

Sandstones is categorised in the group of sedimentary rocks. Sandstones formed from the process of weathering and sedimentation of igneous, metamorphic and previous deposited sediments that have been broken down physically and chemically. The sediments from the weathering process are transported by the agents to the depositional environments. The most significant sandstone depositional environments are continental (alluvial fan, braided stream, meandering stream and Aeolian), transitional (deltaic and coastal barrier islands, tidal channels, and Aeolian and transgressive marine), and deep marine (turbidities related to submarine canyon-fan systems) (Blanc, 1977).

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). Reservoirs are subterranean expanses of rock whose pore spaces and fractures are saturated with some combination of oil, water, and other elements and molecules. Two of the reservoir characteristics are porosity and permeability. Porosity is amount of void spaces in the rock and permeability is the ease of fluid through the rock.

Sedimentological and petrophysical properties have to be analysing in understanding the relationship between the reservoir properties with stratigraphic sequences and depositional processes. Integrated sedimentological and petrophysical methods in characterizing sandstone reservoir had been carried out by many authors

(Abdul Hadi, 1995; Castle & Brynes, 2005; Lima & De Ros, 2003; Reifenstuhl, 2002; Shirley et al., 2003; Walton et al., 1986).

2.2 Sedimentology and Facies Characteristics of Sandstone

Facies can be defined as the overall characteristic of rock unit that reflect its origin from other around it. Mineralogy and sedimentary source, fossil content, sedimentary structures, and texture distinguish one facies from another (Oilfield Glossary). In reservoir characterization and reservoir simulation, the facies properties that most significant are the petrophysical characteristics that control the fluid behaviour in the facies (Oilfield Glossary). The term of lithofacies refer to a mappable subdivision of a stratigraphic unit that can be distinguished by its facies or lithology which are the texture, mineralogy, grain size, and the depositional environment that produced it. Lithofacies observed in the core from Orla Petro 41R East Ford Unit well is organic-rich siltstone, laminated sandstone, and structureless or massive sandstones having few laminations but containing floating siltstone clasts, dewatering features, and load structures (Dutton, Flanders, & Barton, 2002).

2.2.1 Sedimentary Structure

Sedimentary structures reflect the hydrodynamics processes during deposition and they are simply divided into primary and secondary classes (Ying, 2007). Stratification is one kind of sedimentary structure. Stratification is defined as layering by sediment deposition (Southard, 2006). Stratification is produced by physical, chemical, and biological processes. The individual layer in a sediment or sedimentary rock that is produced by deposition is called stratum (plural: strata). In the other case, a stratum that is less than one centimetre thick is called a lamina (plural: laminae) and a stratum that is greater than one centimetre thick is called a bed (plural: beds) (Southard, 2006). Hence stratification can be termed either lamination or bedding.

Stratification is observed as differences in nature of the deposit from stratum to stratum, in texture, and/or in composition, and/or even in sedimentary structures. Stratification is one of the most visible and striking features of sedimentary rocks but a few of stratification is subtle and requires care in observation. Lamination in particularly, is always subtle and delicate. There are two kinds of physical stratification features within strata which are planar-stratification and cross-stratification.

2.2.1.1 Cross Bedded

Cross-stratification is applied to any arrangement of strata that are locally inclined at some angle to the planar orientation of the stratification. Bedforms produce a variety of forms of cross-stratification (also primary sedimentary structures) that are very common in the geologic record (Cheel, 2011). Cross-stratification is commonly marked as lamination, within much thicker stratum, that is at least in some places at an angle to the bounding surface of the given thicker stratum (Southard, 2006). Relating to the official division of strata into beds and laminae, cross-stratification can be classified either cross-bedding or cross-lamination.

2.2.1.2 Plane Bedded

Plane bedded is a near-horizontal surface of sand or gravel. There is two type of plane bedded. Upper-stage plane beds are produced by the intense transport of sediment by high-velocity, shallow flows (upper-flow-regime conditions), and characterized by primary current lineation on the sediment surface. Lower-stage plane beds are produced only in coarse sands and gravels by flow conditions broadly similar to those which generate current ripples in finer sand. The lower-stage plane bed exhibits a series of shallow scours on the sediment surface. The accumulation of plane-bedded sediment gives rise to an internal sedimentary structure of horizontal lamination.

The varieties of bedforms are determined by the flow regime under which the bedforms develop. The flow regime can be distinguished into lower flow regime and upper flow regime, partly on the basis of the bedforms that are produced under unidirectional flows. Figure 3 summarizes the main criteria for differentiating these two flow regimes. The lower flow regime is dominated by bedforms that are out of phase with the water surface and the upper flow regime is dominated by bedforms that are in-phase with water (Simon & Richardson, 1961).

Flow Regime	Bedforms	Characteristics
Lower flow regime	Lower plane bed, Ripples, Dunes	• **F** < 0.84-1.0*; • low rate of sediment transport, dominated by contact load; • bedforms out-of-phase with the water surface.
Upper flow regime	Upper plane bed, In-phase waves, Chutes and pools	• **F** > 0.84 - 1.0*; • high rates of sediment transport, high suspended load; • bedforms in-phase with the water surface.

*Note that Simons and Richardson (1961) set **F** < 1.0 for lower flow regime and **F** > 1.0 for upper flow regime. However, subsequent work indicated that in-phase waves began to develop over the range 0.84 < **F** < 1.0. Because in-phase waves were particularly characteristic of the upper flow regime the limiting value of **F** has been adjusted accordingly here.

Figure 3: The flow regime concept of Simons and Richardson (1961)

2.2.2 Lithology and Texture

The lithology of a rock unit is a description of its physical characteristics visible at outcrop, in hand or core samples or with low magnification microscopy, such as colour, texture, grain size, or composition (Lithology, 2012). The texture of sediment refers to the group of properties that describe the individual or bulk characteristics of the particles making up sediment. The texture is included the grain size, grain shape, grain orientation and the secondary properties that are related to other (porosity and permeability). The grain size can be classified into individual and bulk (grain size distribution). The important of these properties are to infer the history of the sediment, the process that acted during transport and deposition of sediment, and the behaviour of sediment.

2.2.2.1 Grain Size

Grain is the fundamental element in sediment. The existed of grain is important to provide the framework of a sediment. Grain size is important to determining the strength of currents that transported the sediment (Ying, 2007). However, most sediment is composed of particles with a variety of irregular shapes and may extend over a range of sizes. Consequences of the irregularities may difficult the grain size measurement. The consistent terminology to describe the size can solve the problem and resulting moderate data.

One of the methods to determine the grain size is measuring the volume of a particle. The shape of particles is neglected during measure the volume of the particle. The volume can be calculate from the relationship of Mass = Volume x Density of the particle or measuring the volume of fluid displaced by the particle when it is immersed in the fluid within a graduated cylinder or beaker.

2.2.2.2 Sorting

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 quantitatively as standard deviation, i.e. spread of the grain size distribution. Sorting gives an indication of the depositional mechanism. Increasing sorting also correlates with increasing permeabilities (Krumbien and Monk, 1942; Beard and Weyl, 1973). A well-sorted grain are about the same size and shape while poorly sorted sand contains grains with different size and shape (Figure 4).

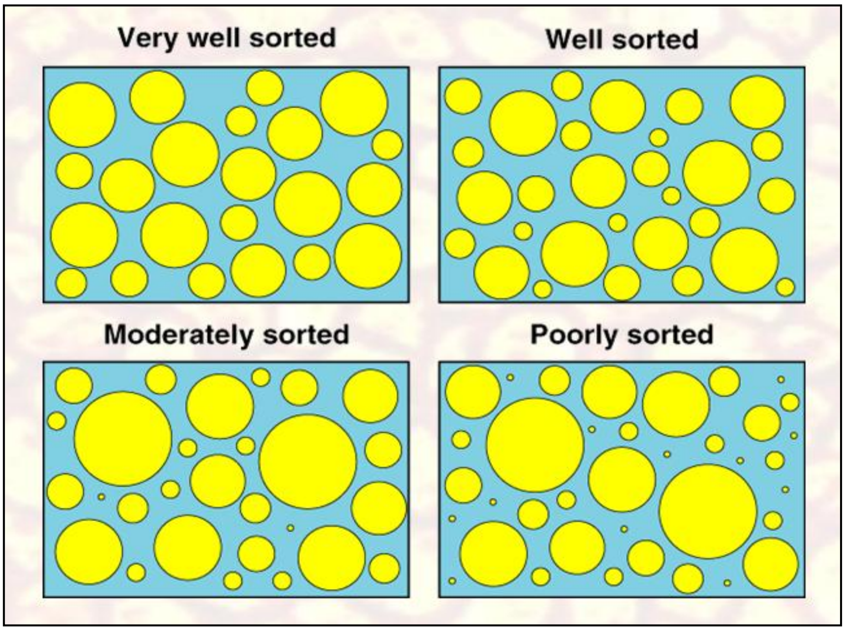

Figure 4: The schematic illustration of various degrees of sorting. After Anstey and Chase, 1974.

2.4 Reservoir and Petrophysical of Sandstone

Petrophysical properties of sedimentary rocks are influenced by porosity, permeability, velocity, and density; these properties are partly controlled by facies characteristics which in turn are related to depositional processes. To predict the movement of hydrocarbon in a reservoir, the transport of contaminants in an underground aquifer or weathering processes and stone decay in numerous architectural structures, these petrophysical properties are very important and needed.

2.4.1 Porosity

Any sediment contains a certain proportion of void space; that is, the proportion of the sediment that is not occupied by particulate solids (i.e., grains) (Cheel, 2011). The term of porosity (P) is defined as the ratio of void volume (Vp) to total or sediment volume (Vt), expressed as a percentage of the total sediment volume.

Porosity (P):

1. Void volume (**Vp**) / Total volume (**Vt**)
2. (Total volume (**Vt**) – Total volume of grains in sediment (**Vg**)) / Total volume (**Vt**)

Porosity is controlled by several factors which are packing density, grain size, sorting, and post burial processes. The packing density is defined as a variety of ways that grain may be arranged in sediment and the spacing of the particles. Packing density can be classified into two different spheres; cubic and rhombohedral packing. The grain size is not having direct effect to porosity of sediment. The effect is shown when relatively larger particles, with high settling velocities, impact on a substrate they tend to jostle the previously-deposited grain into tighter packing (with lower porosity). While in unconsolidated sands porosity tends to increase as grain size decreases. This is because the finer sand tends to be more angular than coarse sand and, therefore, will support a more open packing. Sorting is proportional with porosity; as sorting become poorer (i.e., the standard deviation of the grain size distribution increases) porosity decreases. The reason for this relationship is the poorer the sorting the wider range of grain sizes within sediment and the greater likelihood of finer grains filling the void spaces between larger grains.

The post-burial processes are occurred when sediment has been buried due to subsequent sedimentation on the overlying depositional surface. The burial processes had altered porosity of sediment.

2.4.2 Permeability

Sedimentary rocks consist of grains of solid matter with varying shapes which are more or less cemented, are 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 rock to allow fluids to circulate is called permeability, in the other words; permeability is the ability of the sediment to transmit fluid (Selley, 1998).

Pore throat are the smaller connecting spaces linking pores and providing the more significant restrictions to fluid flow. Permeability describes the property of 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 throat. Grain packing also influences permeability. Open packing shows high porosity and therefore high permeability than closed packing.

2.4.2.1 Anisotropy of Permeability

A sediment or sedimentary rock is defined to be anisotropic with respect to permeability when the magnitude of permeability at a given sample point changes with the direction of fluid flow through the sample (Meyer, 2002). Flow or permeability anisotropy established during the deposition, may be further modified by burial diagenetic processes. Based on recent studies, small-scale laminar structures characteristic of sandstone have a strong influence on highly anisotropic permeability fields. This anisotropy controls single-phase fluid flow as well as two-phase effective mobility of immiscible phase such as oil-water, and provides a framework to upscale the effect of such structures to field-scale grids for reservoir models (Ringrose et al., 1993; Ringrose and Corbett, 1994; Tidwell and Wilson, 1997).

2.4.3 Tortuosity

Tortuosity describes the nature of the fluid pathway through the interconnected pores, and can be thought of as the square of the ratio of the distance actually traveled by a tracer through the pore space to the straight-line distance between the two points (R. Wang*, 2004). In such a system, assuming that the electrical conductivity of the pore fluid does not change, if porosity increases, permeability increases and σ_{ef} increases; if tortuosity increases, permeability decreases and σ_{ef} decreases (Butler).

METHODOLOGY

3.1 Facies Sedimentological Analysis

The outcrops are selected from location that associated with the Nyalau formation and particularly at the south region of Bintulu. The outcrop was built from the same layering of sediment deposition (stratification).

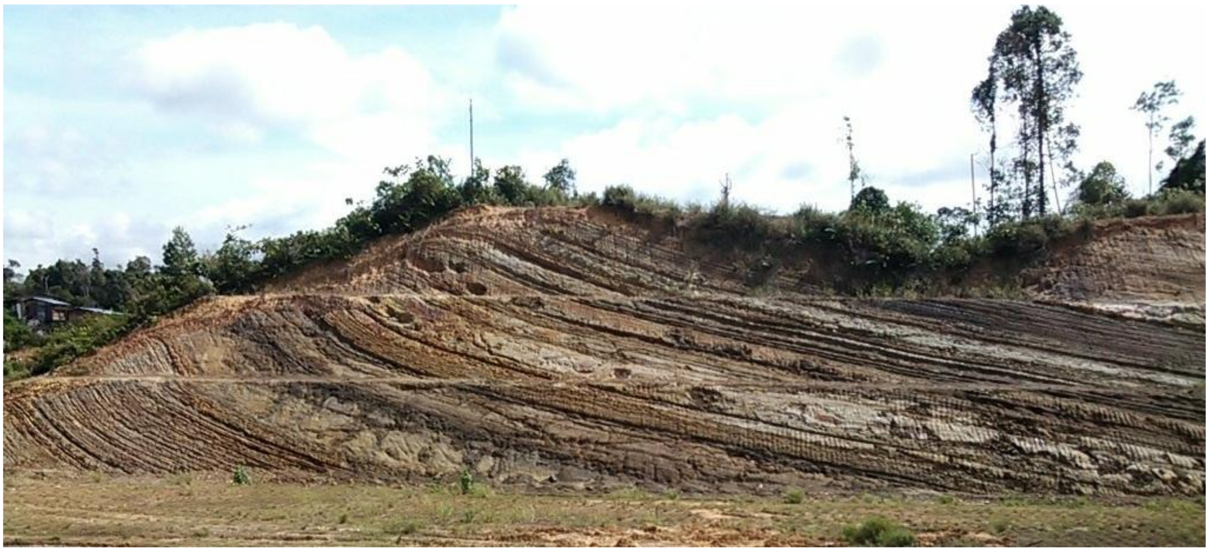

Figure 5: Cross-bedded outcrop from Kidurong road, Bintulu

The outcrop will be divided into different divisions depend on the boundaries in the facies. For example in the analysis of sandstone from Miri formation (Jia & Rahman, 2009), the facies description is investigated on the different cross-stratifications which are low angle-to-hummocky cross-stratification, Trough cross-bedded sandstone, Bioturbated sandstone, and Swaley cross stratified sandstone interbedded with shale/Amalgamated hummocky cross-stratified sandstone. The outcrop facies to be described based on several criteria such as colour, sorting, planar or cross stratification, thickness, fluid processes (Paleocurrent), sedimentary source and mineralogy, and others.

3.2 Sampling

Collecting sandstone samples at selected outcrop around Bintulu, particularly at the south region. Tools like hammer, measurement tape, compass clinometers, portable GPS, and goggle are basic tools to be used in fieldtrip. Hammer is used to break the rock into small fragment. Compass clinometers are used to measure the strike and dip of outcrop. While the bed thickness is measured by the measurement tape. The longitude and latitude of outcrop location is calculated by portable GPS.

3.3 Laboratory Petrophysical testing and Measurements

3.3.1 Grain size

Due to most of sediment is composed of particles with a variety of irregular shapes and may extend over a range of sizes, the consistent terminology to describe the size had been proposed. Several of the terminology are measuring the grain volume and sieving.

3.3.1.1 Sieving Analysis

Sieving analysis is the method that widely used to directly measure the sizes of a large number of grains (samples range from 40 to 75 grams) and is normally limited to particles in the range from as fine as 63 micro meters up to large as 256 mm. The equipment that is used for sieving included shaker and a series of nested, square holed screens (the screen with the largest holes in the top, down the smallest holes on the bottom). The sediment sample is passed through the screens, by shaking, and the weight of the sediment that accumulates on each screen is weighed. The information obtained is not the exactly size of each grain but the frequency of grains (by weight), in a sample, that fall between the range of sizes represented by the square holes in the screen above and in the screen on which the grains are resting. Rotap shakers (Figure 6) are recommended for sieving.

Figure 6: Rotap Shakers

Procedure of sieving:

i. A representative weighed sample is poured into the top sieve which has the largest screen openings. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver.

ii. The column is typically placed in a mechanical shaker. The shaker shakes the column, usually for some fixed amount of time. After the shaking is complete the material on each sieve is weighed. The weight of the sample of each sieve is then divided by the total weight to give a percentage retained on each sieve.

iii. The size of the average particles on each sieve then being analysis to get the cut-point or specific size range captured on screen.

3.3.2 Measurement of Porosity and permeability

3.3.2.1 Specific Gravity Measurement

Before proceed to Mercury Pressure Porosimeter test, the sample density have to be determined. There are several methods to determine the sample density and based on this project, the author had implemented two of methods to measure the sample density. The methods are:

1. Small rectangle of sandstone sample.

   First the fragment of sample is carved until the shape become rectangle. Then the length, width, and height of rectangle sample are measured by using a ruler. The volume of rectangle sample is calculated and the rectangle sample is weighted. The density of rectangle sample is calculated by divided weight of sample over volume of sample. This method is recommended to the sample that porous and brittle.

2. Water displacement.
   First and foremost, a fragment of sample is weighted up on the electronic weight. After that, the figure 11 is set up and places a fragment of sample on the holder that submerges in water. Then record the submerge fragment sample weight. The density of a fragment sample is equal to weight of fragment sample in air over weight of fragment sample in air minus weight of fragment sample in water.

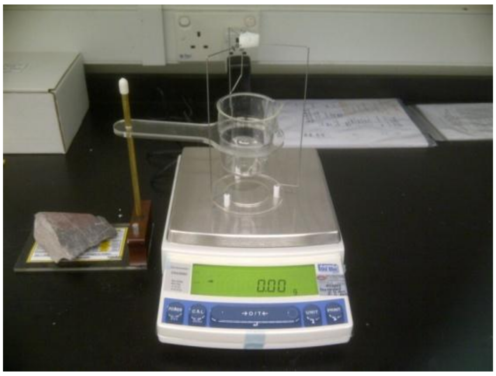

Figure 7: *Water displacement equipment setup*

3.3.2.2 Mercury Pressure Porosimeter

Mercury Pressure Porosimeter is operated by Pascal 140 and Pascal 240. PASCAL is referred as Pressurization by Automatic Speedup and Continuous Adjustment Logic. The operation is begun by Pascal 140 and following with Pascal 240. The modularity of the Pascal system (Pascal 140 and Pascal 240) approach as the data from the low pressure porosimetry can be then combined with the high pressure ones to get a complete porosity spectrum of the material. Mercury is used in both of machines as intrusion liquid. Mercury is a hazardous material thus should be handled with the same care that any other hazardous laboratory chemical is given. Both of machine is controlled and monitored by software in the computer.

The Pascal 140 has a dual role. First, it prepares the sample and sample holder prior the analysis (degassing under vacuum and mercury filling). Second, the Pascal 140 is to carry out low-pressure porosimetry measurements. Its modular concept allows using it as stand alone or together with the other high pressure porosimeters (Pascal 240). Pascal 240 takes over the porosity experiment after the low pressure test is done by the Pascal 140. It is capable to run experiments from atmospheric pressure up to 200 MPa thus characterizing materials with a porosity ranging from 0.0074++ up to 15++ pore dimension.

Figure8: Pascal 240

Figure 9: Pascal 140

Figure 10: Computer that monitoring the Mercury Porosimeter operation

Figure 11: Fume hood in handling Mercury disposal

3.3.2.2.1 Pascal 140 Operation Procedures (Sampling Analysis)

1. Take an empty dilatometer fill the sample and weight it.
2. Place the electrode over the dilatometer and place the dilatometer into Pascal 140.
3. Set the type of dilatometer, maximum pressure, ramp speed and end analysis pressure and save it as method file.
4. Select the "START SAMPLE" on the application and key in the setting for sample analysis.
5. Key in the details like company, operator name, sample weight, sample density, select blank file and experiment temperature.
6. Load the blank file and create the sample file name and click "START" button to start the sample analysis.
7. When analysis completed, press the "DOWNLOAD" button to download the result from equipment and save it in the sample name.

3.3.2.2.2 Pascal 240 Operation Procedures (Sampling Analysis)

1. Transfer the dilatometer from Pascal 140 and place it into the autoclave of Pascal 240.

2. Using a syringe to fill the top portion of dilatometer's stem with dielectric oil in order to remove air contain inside the stem and place the electrode over the dilatometer.

3. Open the lower waste valve until the rd-link mark.

4. Open the upper vent valve until beyond the red-line (End position).

5. Press the "DOWN" button and close the autoclave.

6. Close the upper vent valve until the red-line mark.

7. Press the "FILL" button to remove the air bubbles, normally this will take around 5 to 10 minutes.

8. Make sure no air bubbles inside the inlet tube of the upper vent valve and press the "FILL" button to filling process.

9. CLOSE the lower waste valve and then the upper vent valve.

10. Set the type of dilatometer, maximum pressure, pump speed and save it as method file.

11. Select the "START" button to key in the setting for sample analysis.

12. Click "IMPORT PARAMETER" to import the parameter from Pascal 140 and load the blank file.

13. Create the file name and click "START" button to start the sample analysis.

14. When analysis completed, press the "DOWNLOAD" button to download the result from equipment and save it in the sample name.

RESULT AND DISCUSSION

4.1 Facies Description of Outcrops from the South Region of Bintulu

4.1.1 Introduction

The purposes of fieldtrip to Bintulu is to do sampling process on the outcrop around south region of Bintulu and to expose the author the example of reservoir system like clean sandstone. The fieldtrip was held on 24 February to 27 February 2012. The area of study of author's focused on the south region of Bintulu that included the outcrops from **Sg. Mas, Sambling,** and **STM Beach.** Facies description is interpreted as the observation of physical features in the rocks. The physical features are lithology and sedimentary structures. Lithology is analysed based on the mineral content, grain size, texture and colour of rock while the sedimentary structures are those structure formed during sediment deposition such as cross bedding and ripple mark.

4.1.2 Sungai Mas Outcrop

From the physical observation, sandstone is dominant on this outcrop. Typically, minerals in sandstone will be quartz, clay mineral and feldspar. Within bedding structure, it is found the cross bedded sandstones. On the top of cross-bedded sandstones, it had clasts of older weathered and eroded rocks. There are observed impurities (red colour of Iron Oxides) around the sandstones and it might be transported by water flow across the sandstones. Samples are taken from the cross bedded of sandstones for further analysis (Sieving and Mercury Pressure Porosimeter).

4.1.3 Sambling Estate Outcrop

Figure 12: *Sambling Graphic log of outcrop*

Number of Facies	Texture	Sedimentary structure	Description	Remark
Facies 1			Coal beds	
Facies 2			Blocky Mudstone and slightly laminated	
Facies 3			Fine Sandstone Top: • Parallel lamination	This zone had good horizontal permeability (Kh). In term of production, a good Kh can produce better horizontally.
			Fine Sandstone Bottom (Heterolithic bedding): • Deposited of muddy layer and sandstone layer. • Wavy parallel lamination	

INDICATOR

Clay, Mudstone

Sandstone

Coal

Paleosol of the outcrop is summarised as the sediments are buried under the coal beds (refer to **APPENDICES 1**) for a certain of time and the sediments have went through the lithification process. The process had changed the sediments into rocks (Facies 2 and Facies 3). The original colour of rocks in Facies 3 is grey but due to water flow had bleached it into white colour.

The outcrop dip is 115^o to north east and 20^o of the strike. The thickness of Facies 3 is 163 cm. From the observation, fine sandstone (refer to **APPENDICES 2**) is dominant in Facies 3. Meanwhile shale is placed within the layer of sandstone as shale debris. Shale debris can be barriers of fluid flow during the production of oil. Besides, the trace fossils are also found in the outcrop such as burrows and ophiamorpha. The trace fossil is useful in determining the consistency of the sediment at the time of its deposition and the energy level of the depositional environment. For example, the existence of ophiamorpha in the outcrop had indicated there was marine environment million years ago. In Sambling Estate, there are 3 samples were taken which are Sambling top, Sambling middle, and Sambling bottom.

4.1.4 STM Beach Outcrop

From the physical observation on the outcrop, the sedimentary structures founded here are ripples and cross stratification (Depositional structures). In additional, the depositional structures are occurred on the upper surface and within of beds. Ripples are made from the movement of wind and water onto sediments. The ripples founded in the outcrop are sandstone ripples with wavy and irregular of lamination (refer to **APPENDICES 3 and 4**). Based on appendices 3, in between of ripples are formed wavy and irregular laminations. The cross-stratification to identify on the outcrop is Hummocky Cross-stratification (HCS) and plane lamination of clean sandstone. HCS is characterised by a gently undulating low-angle (less than 10^o to 15^o) cross lamination with the convex upward part the hummock and concave downward part the swale (Tucker, 2003). Plane and parallel lamination is founded internal of clean sandstone layers (refer to **APPENDICES 5**). Clean sandstone layer can be distinguished from the coarse sandstone lamination to the fine sandstone lamination. In STM Beach, the samples were taken from the top and middle of parallel lamination and HCS.

4.1.5 Samples from the south region of Bintulu

List of samples are refer to **APPENDICES 6.**

4.2 Laboratories Analysis

4.2.1 Sieving Analysis

The Sieving Analysis had been done on Sambling and Sg. Mas sample. The **APPENDICES 7** and **8** are shown the result from sieving test of both samples. From the result, the graphs are plotted based on weight percentage over sieving mesh size. Figure 13 and 14 are shown the plotting.

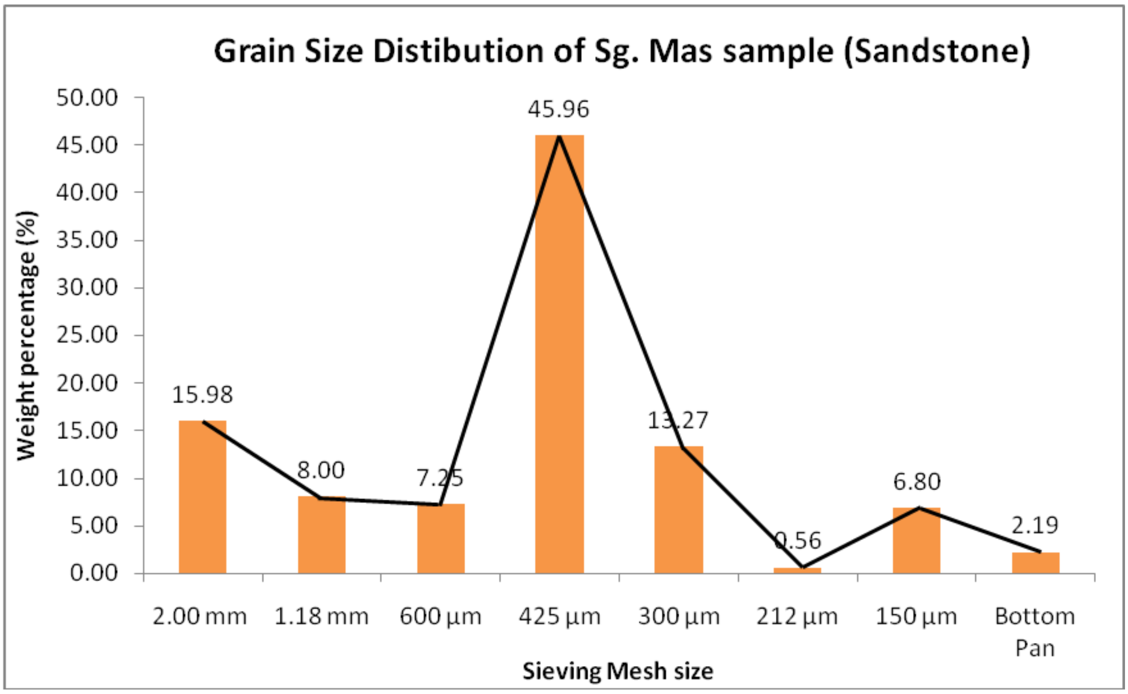

Figure 13: *Weight percentage over sieving mesh size for Sg. Mas sample*

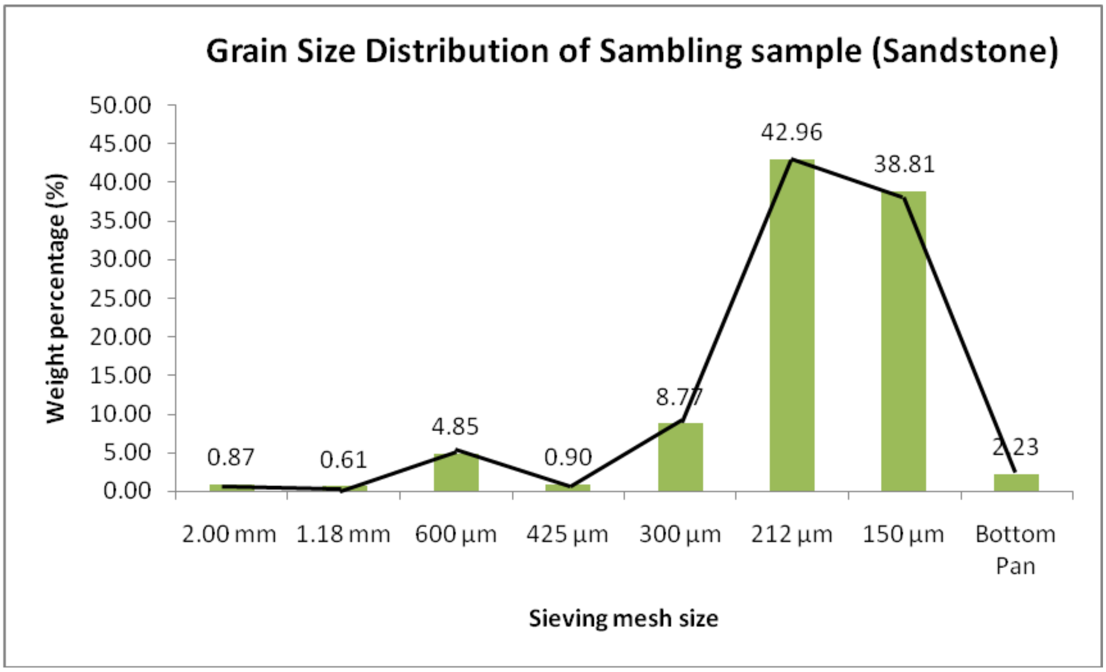

Figure 14: *Weight percentage over sieving mesh size for Sambling sample*

From the graph of weight percentage vs. sieving mesh size, the Sg. Mas sandstone sample is mostly accumulate on the sieving mesh of 425 µm while the Sambling sandstone sample at the sieving mesh of 212 µm. Based on Wentworth size class, Sg. Mas sandstone sample can be defined as medium sand while Sambling sandstone sample as fine sand.

Sorting is defined by look into the trendline of weight percentage over mean of sieving mesh size. In a quantitative sense, sorting is a measure of the standard deviation from the mean grain size. Thus, on a histogram or frequency curve, a narrow peak has a low standard deviation and would represent well sorted material. A broad, spread-out frequency curve would indicate poorly sorted sediment (Nelson, 2000). Sg. Mas and Sambling trendlines are narrow peak and it can be classified as well sorted.

4.2.2 Mercury Pressure Porosimeter Analysis

The mercury pressure porosimeter had been tested on seven of sandstone samples which are Sambling (top, middle, and bottom), Sg. Mas, and STM Beach (Parallel lamination (middle) and HCS (top and middle). There are several data are set to be constant and shown in Figure 15.

Data	Value
Mercury surface tension (N/m)	0.48
Mercury contact angle (^{o})	140.00
Maximum test pressure (Mpa)	200.00
Speed of mercury injection	7.00
Temperature of test (^{o}c)	25.00
Mercury density at test (g/cm^3)	13.534
Dilatometer cone length (mm)	22.00
Dilatometer electrode gap (mm)	5.00
Dilatometer stem radius (mm)	1.50
Dilatometer weight (g)	44.00
Blank filling volume (mm^3)	489.00

Figure 15: *Constant data in Mercury pressure porosimeter test*

The constant data are important to ensure the result of the all tests to be accurate and precise. Each of samples is taken around 2 hours to be tested. The result of the tests is shown in Figure 16.

Sample	Porosity (%) Accessible Porosity (effective)	Permeability (mD)	Tortuosity
Sambling Top	29.03	5.442	1.996
Sambling Middle	32.18	5.442	2.246
Sambling Bottom	30.68	413.3	2.203
Sg. Mas	28.45	5.442	2.025
STM Beach Outcrop: Parallel Lamination Middle	25.29	413.3	2.293
STM Beach Outcrop: HCS Top	27.84	413.3	2.059
STM Beach Outcrop: HCS Middle	20.65	413.3	2.129

Figure 16: *Result of Mercury Pressure Porosimeter for 7 samples of sandstone*

Most of the samples are having the accessible porosity on the range of 20% to 32%. The samples permeability is on the range of 5.442 mD to 413.3 mD and tortuosity of samples are in the range of 1.996 to 2.293. After analyzing the result, it seems that the value of permeability is not relevant. The samples are resulted with only two values of permeability, 5.442 mD and 413.3 mD. Furthermore, the sample with high porosity is measured to have low permeability. For example like sample from Sambling middle, the porosity is 32.18 % while permeability is 5.442 mD. Generally, sample that consist high porosity will have high permeability. So the author assumed that permeability data are not accurate and the data are not appropriate for comparing samples. Tortuosity data are different among the samples. Based on Butler, In such a system, assuming that the electrical conductivity of the pore fluid does not change, if porosity increases, permeability increases and σ_{ef} increases; if tortuosity increases, permeability decreases and σ_{ef} decreases. Hence the high tortuosity will have low permeability and vice-versa. From figure 16, the author had observed that **Sambling bottom** had the best value of porosity (30.68 %) and tortuosity (2.203) compare to other.

The Sambling bottom had the best result among other samples as the porosity (30.68%) and tortuosity (2.203). Based on the facies description and sieving analysis stated that Sambling bottom is fine sandstone and well sorted. The depositional structure to be found on Sambling bottom sample is wavy and parallel laminations. Beach sands and dune sands tend to be well-sorted because the energy of the waves or wind is usually rather constant (Nelson, 2000). Well sorted sandstone had better uniformity of size than poorly sorted sandstone. Hence well sorted sandstone is capable to provide larger volume of voids. The parallel lamination had good horizontal permeability (Kh). In term of production, good horizontal permeability (Kh) is best performance when produce oil and gas horizontally. So the high porosity and permeability of Sambling bottom is influenced by the grain size of sandstone (fine sandstone), sorting (well sorted) and depositional structure (wavy and parallel lamination).

STM Beach outcrop samples are taken from the HCS and parallel lamination. HCS contained concretions of abundant mica and plant detritus in the tops of many laminae. Concretion is compact mass of sedimentary rock formed by the precipitation of mineral cement within the spaces between the sediment grains. The concretion in the outcrop samples probably the reason of lower porosity than other outcrops. The compact mass of sedimentary rocks are closed the voids and hence affected the porosity value. Plane and parallel lamination is given a good path for fluid to flow horizontally. Therefore, the production of fluid (oil and gas) is highly performed horizontally.

Sg. Mas sample is taken from the cross bedded section of sandstone. At the top of the sample location had clasts. The clasts might be able to act as barrier in fluid flowing and it will affect the permeability. The sieving analysis is analyses that Sg. Mas sample is medium sandstone and the sorting is well sorted. Well sorted sandstone is given a better volume of voids space due to the uniformity of size. Well sorted sandstone possibly will have high porosity. Therefore, it is shown even the porosity is high it does not meant the permeability is also high. The barrier may lower the permeability.

Recommendation

Besides to improve the understanding of facies and reservoir characteristics on cross bedded and plane bedded sandstone is suggested to do the fieldtrip. From the fieldtrip, the participants can observe the lithology and sedimentary structures of rock. Afterward samples from the outcrop are suggested to undergo the laboratory tests such as the Sieving process, POROPERM, Scanning Electron Microscope (SEM) and others. In determining sample mineralogy is recommended to use SEM to gain better result.

Moreover, UTP is suggested to give the priority to use equipment for Final Year Project (FYP) students compare to other due to time limitation. UTP is also recommended to open the topic bidding session before semester start. Instead of open during the semester start, it will delay research process for students to understand their topic. To complete the project perfectly, the period of project must be sufficient. The current period is given less than 8 months, 4 months for FYP 1 and the remaining months for FYP 2. In this project, the author had to wait for getting the verification of fieldtrip and the delay had affected the project schedule as planned during FYP 1. The project schedule or Gantt chart can be referring in **APPENDICES 9**.

The laboratory tests like SEM and POROPERM require the reservation before the students are allow running it. SEM is open the reservation every first of month while POROPERM is having long of queue. The author can not to examine the samples with SEM because the open day to reserve it had passed when the samples is arrived. The porous and brittle of samples had resisted the samples from to be coring and without the core plugs, POROPERM test can not to implement.

In conclusion, the major transformations in certain aspects are capable to help students to achieve better outcomes and encourage students to strive the project goal.

Conclusion

The objective of this project is to identify the planar and cross stratification in Nyalau formation especially at the south region of Bintulu and to study the sediment facies of outcrops based on the observation of bedding, sedimentary structures, sediment texture and fabric, sediment composition and colour and other. The objective is also to find out the best sample among the clean sandstone samples from the south region of Bintulu that contain high porosity and permeability and well sorted. The first objective is shown by the facies description of Sg. Mas outcrop (cross-bedded), Sambling outcrop (wavy and parallel lamination) and STM Beach outcrop (HCS and plane and parallel lamination). The second objective is proof by the result of facies description for each outcrops and the sieving analysis of several samples which are Sg. Mas and Sambling. Sg. Mas sample is classified as medium sandstone while Sambling sample is fine sandstone. The sorting for both samples is well sorted. The last objective is achieved by proving the good result of porosity and tortuosity from Sambling bottom. The outcrop is potentially to be a reservoir and will encounter with least problem in production.

In order to achieve the objectives, all the experimental framework are carefully prepared, which is believe can be completed within the time frame of the research, and also taking into consideration of the availability of the equipment and, materials. Last but not least, it is hope that the expected results can be used as guidance for exploration and production operation in the future.

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APPENDICES

Appendices 1: Sambling Estate coal bed at the top of other facies

Appendices 2: Clean sandstone sample from Sambling Estate is already been cut for showing the texture

Appendices 3: STM Beach sandstone ripple with wavy and irregular laminations

Appendices 4: Wavy STM Beach ripples show it weak line

Appendices 5: STM Beach plane and parallel lamination within the fine sandstone

location	Type of rock sample	Number of sample	Remark
Sg. Mas	Sandstone	2	The samples are taken from the cross bedded sandstone outcrop.
Sambling Estate	Sandstone The samples are taken from: i. Top section ii. Middle section iii. Bottom section	 3 1 2	Observation on the outcrop: 1. The overall of the outcrop is dominated with sandstone 2. Shale debris 3. Burrows 4. Ophiomorpha 5. A bit of coal
STM Beach	Sandstone		Observation on the outcrop: 1. Ripple mark with wavy and irregular lamination 2. Cross lamination internally 3. HCS 4. Clean sandstone Note: - Clean sandstone is a good reservoir system.
	Samples taken from HCS (Hummocky Cross Stratification): i. Top section ii. Middle section	 1 1	
	Sample taken from parallel lamination: i. Top section ii. Middle section	 2 1	

Appendices 6: List of samples that took from the south region of Bintulu

Sg. Mas outcrop

Sieving Mesh Size	Weight of beaker with sand (gram)	Weight of empty beaker (gram)	Weight of sand (gram)	Cumulative weight of sand (gram)	Weight percent (%)	Cumulative weight percent (%)
2.00 mm	602.38	469.00	133.38	133.38	15.98	15.98
1.18 mm	502.52	435.74	66.78	200.16	8.00	23.98
600 µm	463.63	403.14	60.49	260.65	7.25	31.23
425 µm	762.45	378.89	383.56	644.21	45.96	77.19
300 µm	481.90	371.15	110.75	754.96	13.27	90.45
212 µm	349.60	344.94	4.66	759.62	0.56	91.01
150 µm	390.21	333.46	56.75	816.37	6.80	97.81
Bottom Pan	411.86	393.60	18.26	834.63	2.19	100.00

Total weight of sand before sieving: 850 gram
Time of sieving: 50 minutes

Appendices 7: Sieving result for Sg. Mas sample

Sambling outcrop

Sieving Mesh Size	Weight of beaker with sand (gram)	Weight of empty beaker (gram)	Weight of sand (gram)	Cumulative weight of sand (gram)	Weight percent (%)	Cumulative weight percent (%)
2.00 mm	472.96	469.10	3.86	3.86	0.87	0.87
1.18 mm	438.52	435.81	2.71	6.57	0.61	1.47
600 µm	424.94	403.28	21.66	28.23	4.85	6.33
425 µm	383.13	379.12	4.01	32.24	0.90	7.23
300 µm	410.37	371.26	39.11	71.35	8.77	15.99
212 µm	536.15	344.47	191.68	263.03	42.96	58.95
150 µm	506.68	333.52	173.16	436.19	38.81	97.77
Bottom Pan	403.60	393.63	9.97	446.16	2.23	100.00

Total weight of sand before sieving: 450 gram
Time of sieving: 30 minutes

Appendices 8: Sieving result for Sambling sample

APPENDICES 9: Gantt chart for the whole project

FYP 1 and FYP 2

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection / Proposal							SEMESTER BREAK							
2	Preliminary research work : Literature review														
3	Submission of Proposal Defense Report														
4	Proposal Defense (Oral Presentation)														
5	Submission of Interim Draft Report														
6	Submission of Interim Report														

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Research work Continues: Literature review	■	■	■	■	■	■									
2	Fieldtrip to Bintulu			■	■											
3	Submission of Progress Report								●							
4	Laboratory Work Continues															
	1. **Sedimentology** Sieving Analysis					■	■	SEMESTER BREAK	■	■	■					
	2. **Petrography** Mercury Porosity Porosimeter:								■	■	■					
5	Pre-EDX											●				
6	Submission of Draft Report												●			
7	Submission of Dissertation (soft bound)													●		
8	Submission of Technical Paper													●		
9	Oral Presentation														●	
10	Submission of Project Dissertation (Hard Bound)															●