PETROPHYSICAL PROPERTIES IN LIMESTONES AT GUNUNG KANTAN SUNGAI SIPUT, PERAK, MALAYSIA

By

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

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CERTIFICATION OF APPROVAL

PETROPHYSICAL PROPERTIES IN LIMESTONES AT GUNUNG KANTAN SUNGAI SIPUT , PERAK, MALAYSIA

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A project dissertation submitted to the
Petroleum Engineering Programme
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in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
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Approved by,

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(Dr. Chow Weng Sum)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
April 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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ABSTRACT

Determination of the petrophysical properties in carbonate reservoirs takes high priority as accurate measurements of the petrophysical properties allow the simulation of the flow of the reservoir. The objective of this project is to determine the petrophysical properties of limestone formation in Gunung Kantan, Sungai Siput, Perak. The petrophysical properties that are involved with the projects are porosity, permeability, sonic velocity, determination of the crystal type and determination of the type of rock. The experimentation of the rock sample begins with collection of the rock sample at Gunung Kantan, Sungai Siput, Perak. A total of 11 samples are taken from 3 different sites around Gunung Kantan.

The first experiment is the determination of the porosity and permeability of rock samples. The experiment is done using the mercury porosimeter as the normal poroperm machine could not detect the amount of porosity and permeability that exist within the rock samples. The result of the experiment is that the rock samples contain a small amount of porosity (max. 6 %) and small amount of permeability (max. 0.14 mD).

The second experiment is the determination of the type of the rock. In this experiment author prepares several thin section from the rock samples and determine the rock type by microscopic sketch approved by the lab assistant. The rock samples were found to be from packstone type which contains grain-supported structure within the presence of mud. The determination of type of rock also involves an experiment with the X-Ray Diffraction. The experiment uses powder from the rock samples and the result from the experiment is that the rock samples are limestone with the presence of a small amount of magnesium.

The third experiment is the determination of the grain shape. In the experiment, author prepares several samples for Scanning Electron Microscope. The experiment objective is to find the type of crystal that exists within the rock samples. The result of the experiment is there are two types of crystal that exists within the rock samples which is compact anhedral crystal and micro rhombic polyhedral crystal.

The last experiment within the project is the determination of the sonic velocity of the rock samples. The author prepares all 11 samples to be tested in s-wave velocity and p-wave velocity in the experiment. The results of the experiment are the s-wave velocity is around 2000-3000 m/s and p-wave velocity is around 4000-5500 m/s. The relationship between porosity and p-wave velocity is observed and a pattern emerges from the relationship. The pattern is that the lower the porosity of the sample, the higher the p-wave velocity. This is because sound wave travels better in solid medium than air pockets. The experiments determine the porosity, permeability, rock type, crystal type and sonic velocity of the rock samples thus fulfilling the objective of the project.

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In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, author managed to complete the Final Year Project I and II in partial fulfilment of the requirement for the Bachelor of Engineering (Hons) in Petroleum Engineering at Universiti Teknologi PETRONAS.

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Deepest gratitude also goes to the names below, who's continuous support, and proactive leadership have truly been a great inspiration to author.

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(Muhammad Syahir Bin Abdullah)

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NOMENCLATURE

DIA = Digital Image Analyzing

$CaCO_3$ = Calcium Carbonate

He = Helium

P-wave = Primary wave or Compressional wave

S-wave = Secondary wave or Shear wave

Si_2 = Amorphous Silica

V_p = Compressional wave velocity

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Limestone is a kind of carbonate sedimentary rock predominantly composed of calcite of organic, chemical or detrital origin. Pore system in limestone is very complex due to its biological origin, chemical reactivity and depositional method. Limestone rocks usually more heterogeneous than siliciclastic sedimentary rocks thus may contain different classes of porosity.

Porosity in heterogeneous reservoir is divided by two main pore systems: macropore and micropore. Micropore is important as it can provide a pathway for connected microporous grains to macropores. Porosity can occur in grain, cement and matrix and it is related to the depositional and diagenetic history of the carbonate revervoir.

The quantification of porosity of limestone of Sungai Siput , Perak leads to determining its structure empirical relationship with permeability and sonic velocity. These relationships can be used for a better understanding of the reservoir systems.

The relationship between porosity and permeability of the limestone is assumed to be an inverse relationship were the higher the porosity the lower the permeability of the structure. Porosity will also have effect on the elastic properties of the rock.

Porosity also reduces the sonic velocity of the limestone. Both P and S wave velocity also shows an inverse relationship with the Porosity. These affects on permeability and sonic velocity in carbonate reservoir will influence the assessment of ultimate recovery of hydrocarbon.

This study concentrates in assessing the effect of porosity against petrophysical properties particularly in terms of permeability and sonic velocity of limestone rocks from Gunung Kantan, Sungai Siput, Perak.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

The Limestone formation is studied to find the amount of porosity in the formation and the effects of the porosity to the formation. This study is using the results from a study of Miocene carbonate reservoir of offshore Sarawak, Malaysia as a reference. The study has revealed an inverse relationship between porosity and permeability.

Sample from carbonate rocks show often a lack of correlation between porosity and other physical properties, particularly permeability and sonic velocity. The high diagenetic potential of carbonates results in intense alteration of the pore structure, which can lead to a decrease of effective porosity for flow and wave propagation. Permeability and elastic properties are strongly related to the rocks pore structure. As a result, samples of equal porosity can exhibit a wide variation of permeability and velocity.

Therefore, based on the examples mentioned above, it is feasible to conduct a study of porosity in limestone rocks and determine the effects they have on the petrophysical properties of the reservoir which will affect the evaluation of the hydrocarbon reserves.

1.2.2 Significant of The Project

This project will allow us to have a look in to the Limestone formation in Sungai Siput, the porosity of the formation will be analyzed by using the mercury porosimeter to find the porosity and permeability of the rock samples. Then X-Ray diffraction and thin section imaging is done to determine the type of rock from the rock samples. Next a sonic velocity test and Scanning Electron Microscope is used to find the sonic velocity and types of crystal exist in the rock samples. After that, analysis on the effects of porosity on the petrophysical properties can be done.

1.3 OBJECTIVES

- To determine the characteristic and petrophysical properties of Paleozoic limestone at Gunung Kantan ,Sungai Siput with relation to pore type for possible correlation to other geophysical or seismic data.

1.4 SCOPE OF STUDY

The scope of study for this project revolves around porosity and its effects on the limestone. The first stage of study consists of researching for industry case studies to understand the theory behind carbonate and limestone formation. Other than that, understanding on the origin and effects of porosity is essential before moving to the second stage of study.

In the second stage, the experiments will be carried out using mercury porosimeter, Scanning Electron Microscope, X-ray Diffraction and sonic velocity. The experiments are done to measure/determine petrophysical properties of the rock samples which includes

- Porosity
- Permeability
- Crystal type
- Rock type
- Sonic velocity

Then, analysis and comparisons will be done base on the data gathered and research studies before.

1.5 THE RELEVANCY OF THE PROJECT

Despite the hydrocarbon they hold, carbonate rocks endure bad reputation for having either complicated interrelationship, or no relationship at all between porosity, permeability and other reservoir properties. Understanding the interrelationship that may exist is a challenge notably in determining the accurate ultimate hydrocarbon recovery.

1.6 FEASIBILITY OF THE PROJECT

This project is fully experimental based. In the time given, the project could be done. This project can be done within seven months given that everything goes fine. The objective can be achieved if the procedures are closely followed.

CHAPTER 2

LITERATURE REVIEW

2.1. LIMESTONE FORMATION

Limestone is a carbonate sedimentary rock consisting mainly of the mineral calcite (calcium carbonate, $CaCO_3$).

Limestone deposits often comprise the aquifers from which we get water, act as stratigraphic reservoirs for oil and gas deposits, and are widely used as industrial minerals. Some limestone is formed almost entirely of skeletons of marine organisms and form very distinctive fossiliferous rocks.

Due to variation in depositional environment and diagenetic processes in forming of carbonate and limestone rocks, they are known to exhibit heterogeneous pore space structures that are both complex and highly variable.

Figure 1: Limestone formation in Sungai Siput

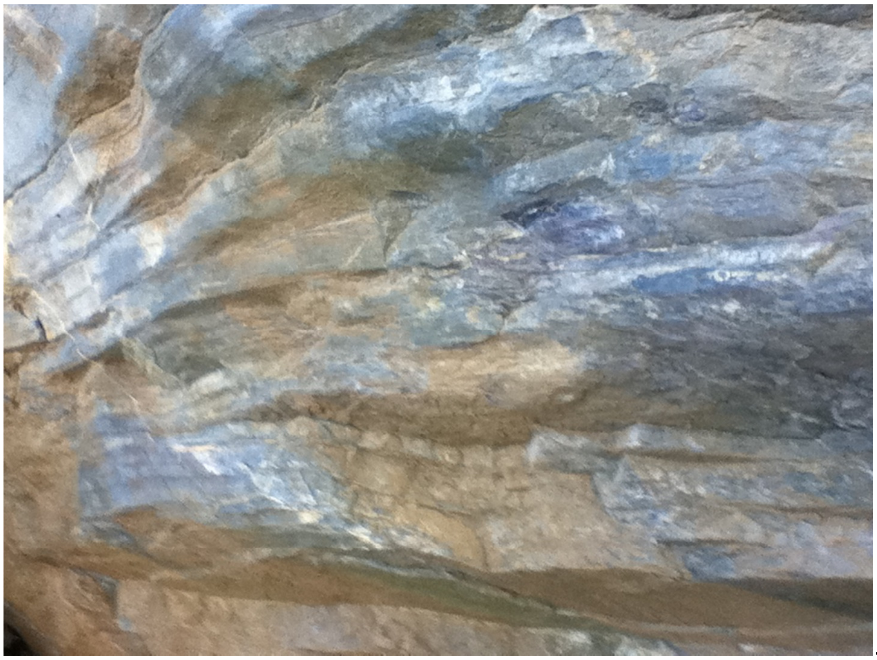

Figure 2: Limestone formation in Sungai Siput

2.2. POROSITY

Porosity is the percentage of a rock or sedimentary deposit that consists of voids and open space. Porosity of a rock is a measure of its ability to hold a fluid.

Carbonates are believed to have complex dual porosity with widely varying proportions of primary and secondary porosity. The secondary porosity may compose of vugs (vugular porosity), moulds (oomoulds and biomoulds), channels, and fractures.

The pore space between sand or carbonate grains as originally deposited is called intergranular porosity, vugular porosity, another well known type, can be formed by leaching of carbonate grains or other soluble material, which results in pores larger than the size of the rocks. Both intergrain and vugular porosity can be detected visually or at low magnification (50X or less). Inspection of both clastic and carbonate samples with the SEM can reveal another type of porosity**: porosity**, No limits on physical measurements have yet been established to define a micropore. Porosity is formed by one of several methods, including recrystallization of grains and oolites, dolomitization, formation of intercrystalline pores, and secondary cementation.

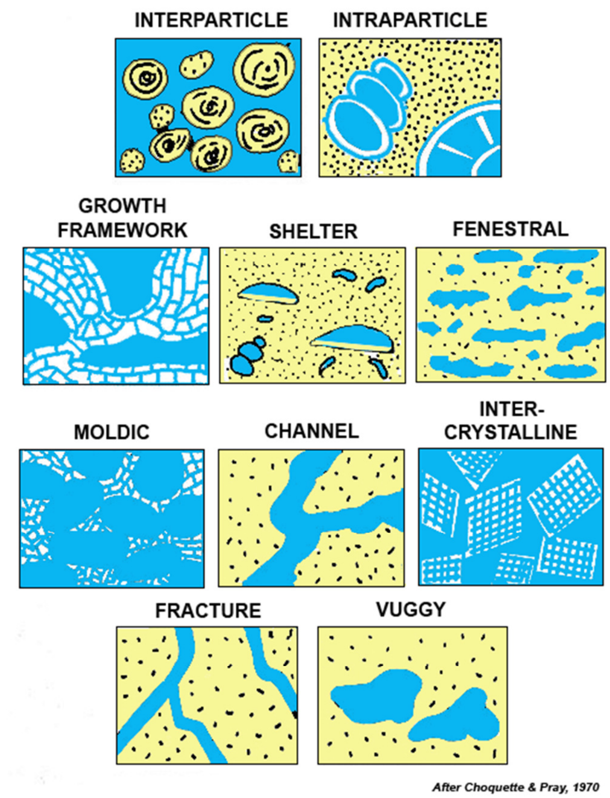

Figure 3:Types of porosity

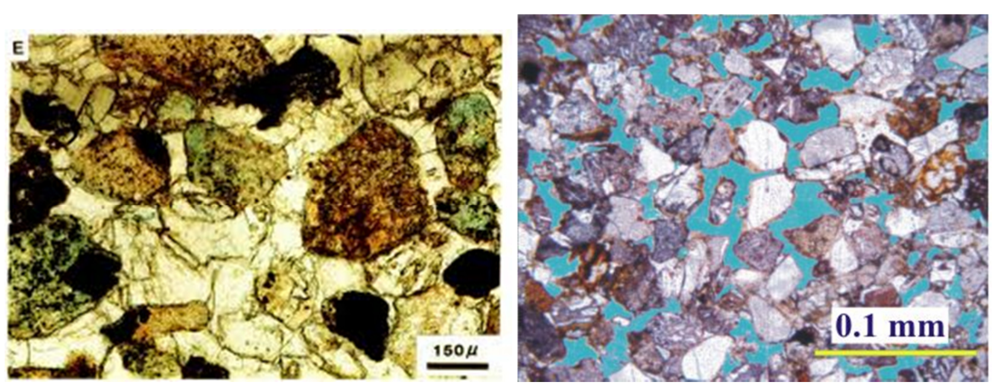

Figure 4: Porosity

2.3. EFFECTS OF POROSITY

When porosity is present in a reservoir, the water held in porosity by capillary attraction tends to be immobile and is called bound water. These bound waters may not be producible. Zones with significant water-filled porosity may contain and produce water free hydrocarbon from porosity even though wireline logs may indicate the zone to be apparently water saturated (as high as 90%) [1], [2], [3].

Traditional pore type classifications (ignoring porosity as pore system) sometimes describe pore structures successfully but fail to quantify the pore system for the correlation to the rock physical properties [4], [5], [6]. Many studies have recognized that acoustic velocity in carbonates is dependent upon pore geometry [7], [8], [9],[10]. Empirical data show that porosity affects permeability and sonic velocity of carbonate reservoirs [11], [13]. Permeability and elastic properties are strongly related to pore structures. Estimation of the amount of porosity from the basic acoustic properties has the potential to improve reservoir quality prediction in carbonate reservoirs with complex pore systems.

2.4. PERMEABILITY

The ability, or measurement of a rock's ability, to transmit fluids, typically measured in darcies or millidarcies. The term was basically defined by Henry Darcy, who showed that the common mathematics of heat transfer could be modified to adequately describe fluid flow in porous media. Formations that transmit fluids readily, such as sandstones, are described as permeable and tend to have many large, well-connected pores. Impermeable formations, such as shales and siltstones, tend to be finer grained or of a mixed grain size, with smaller, fewer, or less interconnected pores.

Absolute permeability is the measurement of the permeability conducted when a single fluid, or phase, is present in the rock. Effective permeability is the ability to preferentially flow or transmit a particular fluid through a rock when other immiscible fluids are present in the reservoir (for example, effective permeability of gas in a gas-water reservoir).

The relative saturations of the fluids as well as the nature of the reservoir affect the effective permeability. Relative permeability is the ratio of effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation. If a single fluid is present in a rock, its relative permeability is 1.0. Calculation of relative permeability allows for comparison of the different abilities of fluids to flow in the presence of each other, since the presence of more than one fluid generally inhibits flow. [12]

2.5. MICRITE TYPE

Four different types of micrite microtextures are classified in this study; these are rounded micrites, subrounded micrites, microrhombic and polyhedral micrites, and compact anhedral micrites. Four different types of micropores are classified based on their pore sizes. These are very fine, fine, medium, and coarse micropores. The classification of microporosity allows its occurrence in carbonate reservoirs to be explained depending on micrite microtextures. The classification of micropores in terms of their micrite microtextural occurrence leads us to define the micropores that are contributing to the permeability of the reservoirs and allow fluid flow in carbonates. [11]

2.6. SONIC VELOCITY

Measurements of compressional-wave velocity (Up) and shear-wave velocity (Us) were performed under confining and pore-fluid pressures, which accurately simulate in situ subsurface conditions. Our study includes carbonates at all stages of diagenetic alteration and complements studies on the velocity of carbonates which were limited to highly lithified, low porosity carbonate rocks (RAFAVICHet al., 1984; WANG et al., 1991) or to pelagic, deep water carbonates (SCHLANGERand DOUGLAS,1974; MILHOLLANDet al., 1980; URMOS and WILKENS, 1993).

Sonic velocity measurements were done in combination with a thorough lithologic and diagenetic examination of thin sections and XRD analysis. Porosity in the samples ranges from 0 to 60% and the depositional environment varies from the protected shallow water platform over reef and platform-marginal sediments to deeper slope deposits.

The correlation of the velocity measurements with the lithology and the mineralogy data enables us to assign depositional and diagenetic stages to characteristic velocities. Furthermore it allows tracing of diagenetic evolution and velocity development from the time of deposition through different burial stages, recognizing that each diagenetic process alters velocity in its characteristic way. [1]

CHAPTER 3

METHODOLOGY

3.1 RESEARCH FLOW

Figure 5 below describes the overall methodology and general flow of this project.

Figure 5. *Flowchart representation of Project Methodology*

3.2 METHODOLOGY

3.2.1 Porosity-Permeability Measurement

To determine the total porosity and permeability of the rock samples, a mercury porosimeter is used. This is because in normal poroperm equipment, limestone which has low porosity and permeability cannot be measured accurately. The result are then tabulated and plotted against each other.

3.2.2 Sonic Velocity Measurement

For the determination of the sonic velocity of the core plug samples. Both P-wave and S-wave velocity of the rock samples will be analyzed. The result of p-wave then will be plotted against both porosity and permeability to see if there are any correlations between them.

3.2.3 X-ray Diffraction (XRD)

For the determination of rock type, several rock samples are crushed into powdered state. The rock powder is then sent to the XRD lab to see what kind of minerals exists in the sample. The result will be used to determine the type of rock collected from the site.

3.2.2 Scanning Electron Microscope (SEM)

For determination of crystal type, several small rock samples are sent to the SEM laboratory to take microscopic images of the surface of the rock. These images are then interpreted by the supervisor to determine the type of crystal.

3.2.2 Thin Section

Several thin sections are prepared from the rock samples. The thin sections are observed under a microscope to determine the type of rock.

3.3 PROJECT ACTIVITIES

Table 1 – Project activities planned for Final Year Project

Activities	Starting Month	Finishing Month
Survey on the availability of suggested Experiment Apparatus (obj.1 & 2)	1st October 2011	7th October 2011
Study on method to obtain porosity from core plug samples and how to quantify them (obj.1 & 2)	5th October 2011	31st October 2011
Field trip to Sungai Siput for obtaining the core plug samples (obj.1)	1st November 2011	8th November 2011
Study on porosity effects on permeability and sonic velocity of the core plug samples (obj.2)	11th November 2011	1st December 2011
Experiment on core plug samples to quantify the amount of porosity (obj.1)	3rd January 2012	10th February 2012
Experiment on effects of porosity on permeability. (obj. 2)	10th February 2012	25th February 2012
Experiment on effects of porosity on sonic velocity. (obj. 2)	25th February 2012	17th March 2012
Analysis of the data	17th March 2012	10th April 2012
Report documentation		

3.4 GANTT CHART & KEY MILESTONES

Table 2 – Gantt chart and Key Milestone through the Final Year Project

	1ST SEM				2ND SEM			
Activity	S	O	N	D	J	F	M	A
Selection of Project Topic	■							
Preliminary Research Work	■							
Submission of Extended Proposal Defense	■							
Survey on the availability of suggested Experiment Apparatus		■						
Purchase unavailability things. Study on how to prepare the solutions.		■						
Defense proposal. Present details on methodology of the experiment.			■					
Sample preparation. Experiment on porosity and permeability.				■	■	■		
Experiment on Thin section and X-Ray Diffraction.					■	■		
Experiment on Scanning Electron Microscope and Sonic Velocity					■	■		
Data analysis					■	■		
Report documentation						■	■	■

3.5 TOOLS

In this project, there are several tools that is used,

1. Mercury porosimeter
    a. To determine the porosity and permeability of the rock samples.

2. X-ray Diffraction (XRD)
    a. To determine the type of mineral exist in the rock samples.

3. Scanning Electron Microscope (SEM)
    a. To capture microscopic images of the surface of the rock samples

4. Sonic Velocity
    a. To determine the velocity of s-wave and p-wave of the rock samples

4.0 RESULTS AND ANALYSIS

4.1 Thin section


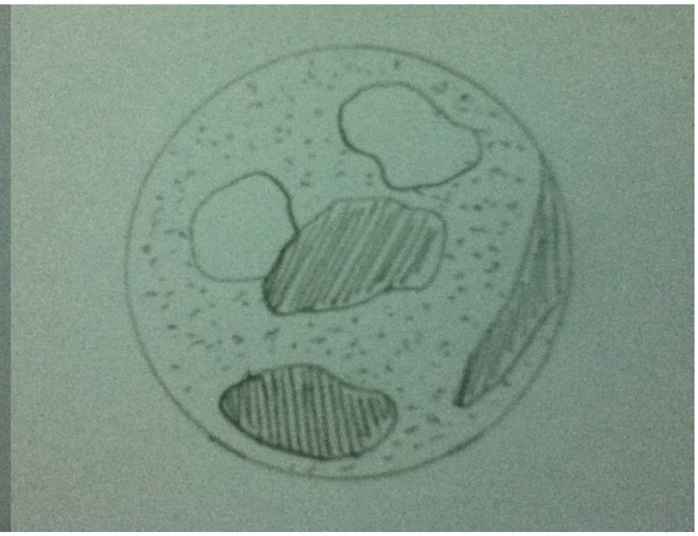

Figure 6: Thin section sample 1

Figure 7: The approximate sketch of thin section sample 1

Analysis: the sample appears to be a packstone as the amount of crystallized grain within the sample is more than 10% which makes it grain supported.


Figure 8: Thin section sample 2

Figure 9: The approximate sketch of thin section sample 2

Analysis: the sample appears to be a packstone as the amount of crystallized grain within the sample is more than 10% which makes it grain supported, the structure of grain is more compacted than the other sample

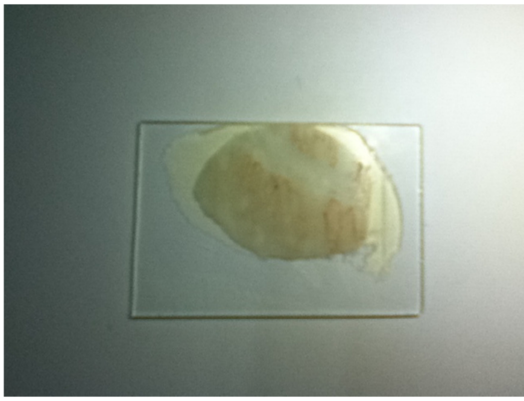
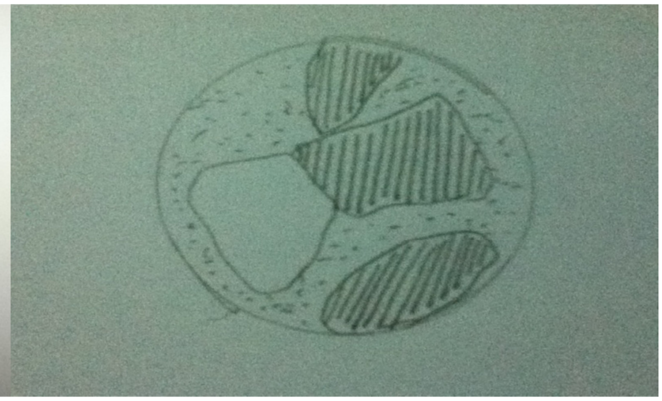

Figure 10: Thin section sample 3

Figure 11: The approximate sketch of thin section sample 3

Analysis: the sample appears to be a packstone as the amount of crystallized grain within the sample is more than 10% which makes it grain supported. the structure of the grain is more angular compared to the other sample


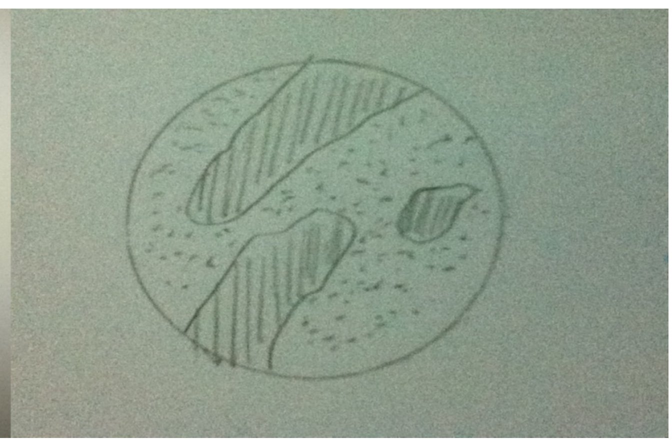

Figure 12: Thin section sample 4

Figure 13: The approximate sketch of thin section sample 4

Analysis: the sample appears to be a packstone as the amount of crystallized grain within the sample is more than 10% which makes it grain supported. The structure of the sample is more elongated than the other sample.

4.2 Porosity and permeability

The porosity and permeability measured from the rock samples are really low with the highest porosity of 6.11% and highest permeability of 0.14 mD. This proved that the rock samples are densely compacted with crystallize grains and mud.

Sample	Porosity (%)	Permeability (mD)
1	4.06	0.07
2	3.36	0.05
3	6.03	0.12
4	4.51	0.06
5	3.77	0.08
6	5.78	0.10
7	6.11	0.14
8	5.54	0.09
9	4.89	0.07
10	4.75	0.07
11	3.03	0.04

Table 3: Porosity and Permeability results

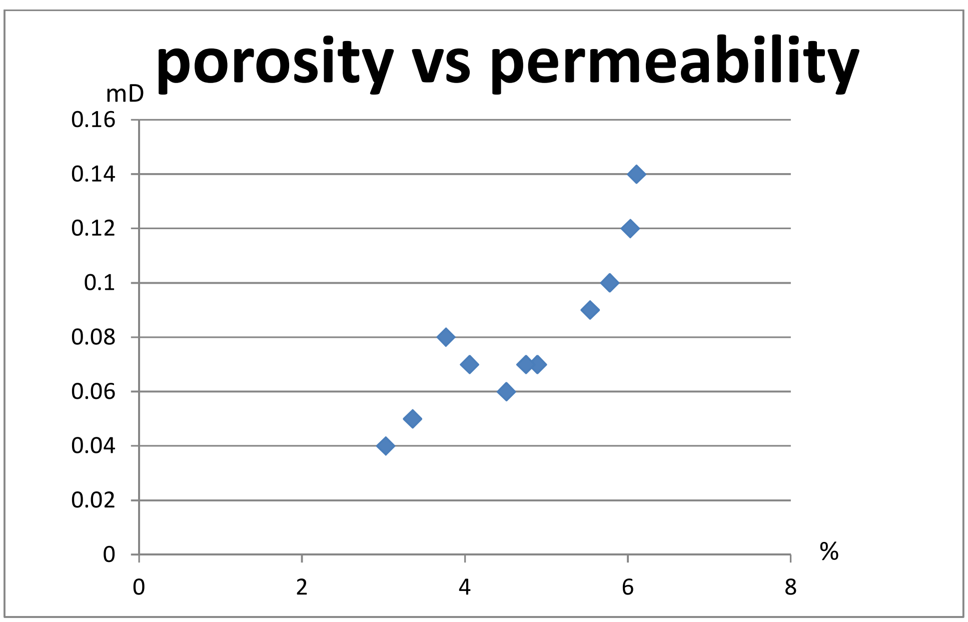

Figure 14: Porosity versus permeability

4.3 Sonic Velocity

The results from sonic velocity experiments conclude that s-wave velocity is around 2000-3000 m/s and p-wave velocity around 4000-5500 m/s.

Sample	s-wave velocity	p-wave velocity
1	3226	5262
2	2760	4591
3	2931	5514
4	3066	4871
5	3018	4934
6	2874	4824
7	2839	4376
8	3105	4804
9	3033	4922
10	2814	4956
11	3018	4723

Table 4: S-wave and P-wave results

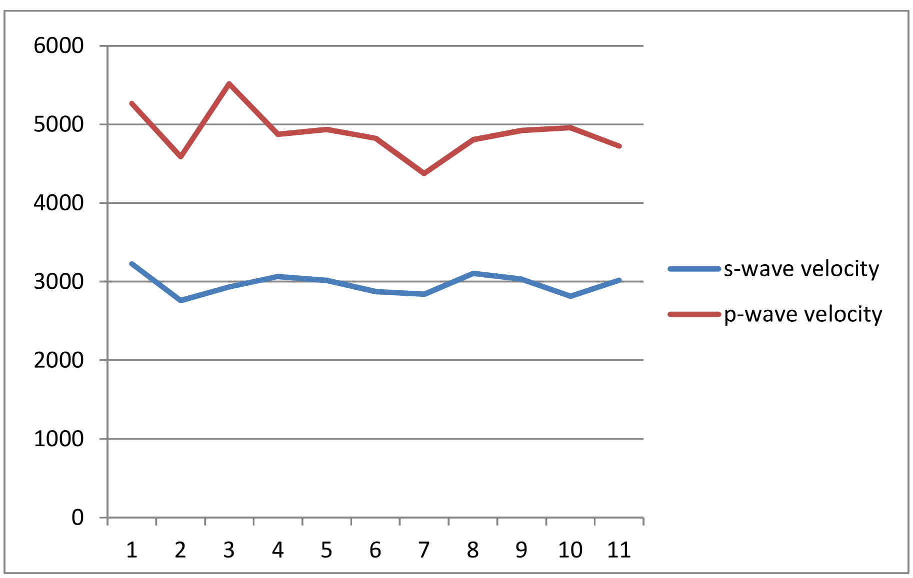

Figure 15: S-wave and P-wave

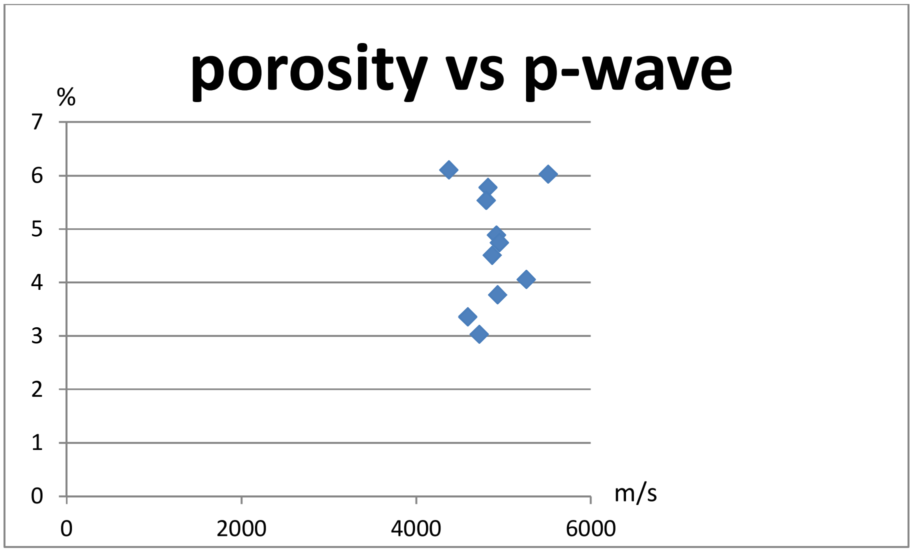

Figure 16: Porosity versus p-wave

The graph of porosity versus p-wave shows us the correlation of the lower the porosity, the higher the velocity.

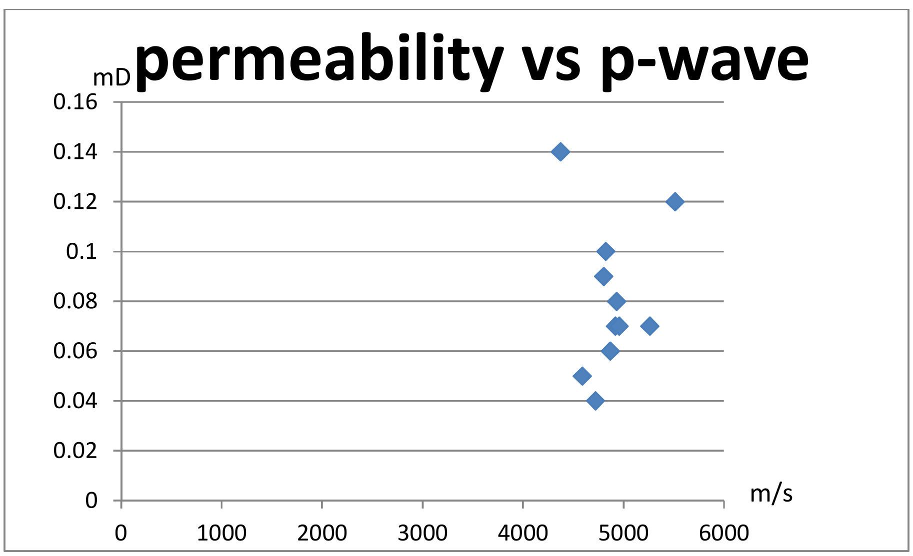

Figure 17: Permeability versus p-wave

The permeability versus p-wave graph shows us that there are no correlation between permeability and p-wave velocity.

4.4 SEM (Scanning electron microscope)

- The results of the Scanning Electron Microscope show that there are two type of crystal structure that exists on the surface of the rock samples. They are micro-rhombic polyhedral crystal and compact anhedral crystal. Below are some images taken from the experiment.[using the Classification of microtexture / Rahman et al./ (2011)]

Micro Rhombic Polyhedral

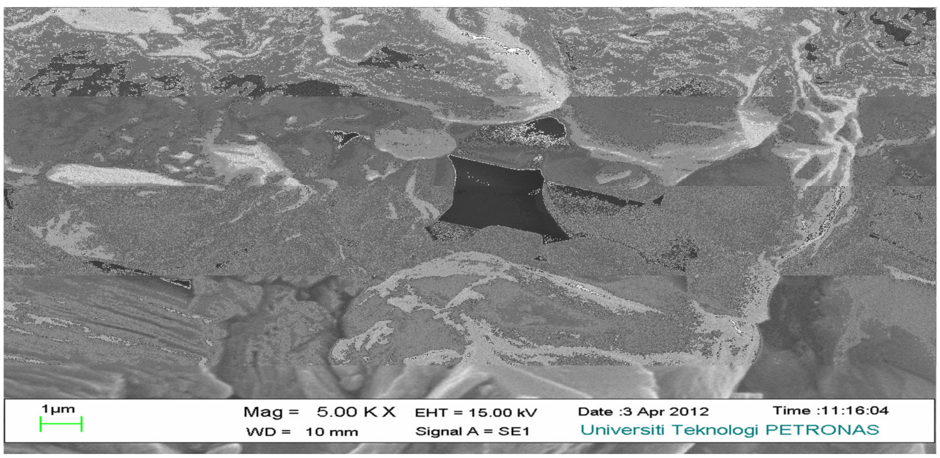

Figure 18: Image from sample 1

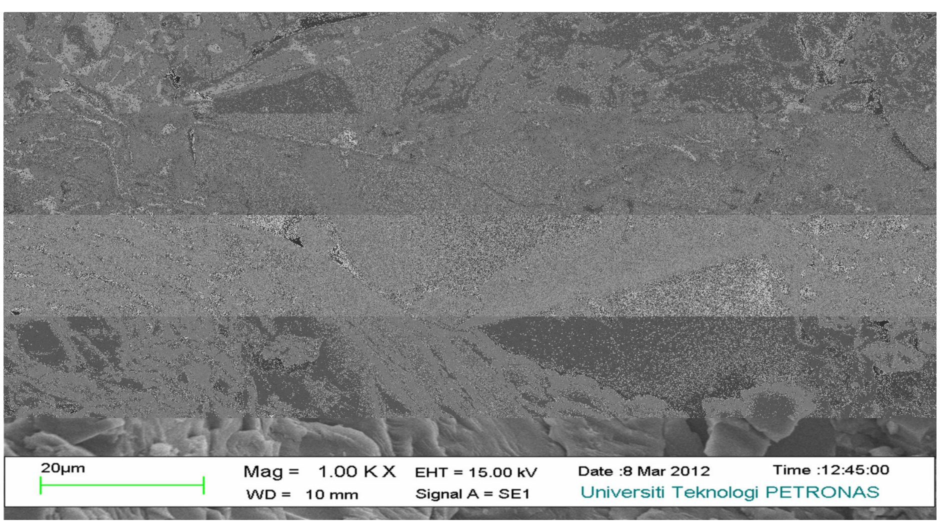

Figure 19: image from sample 1

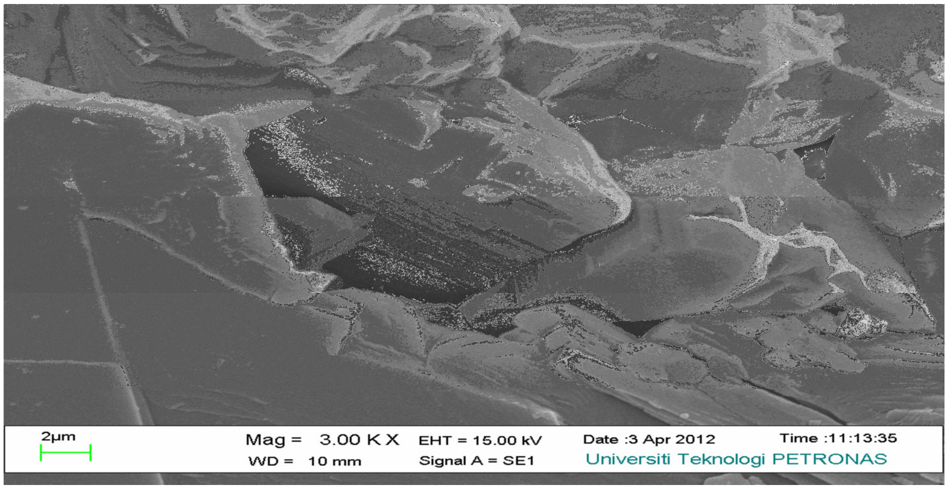

Figure 20: image from sample 3

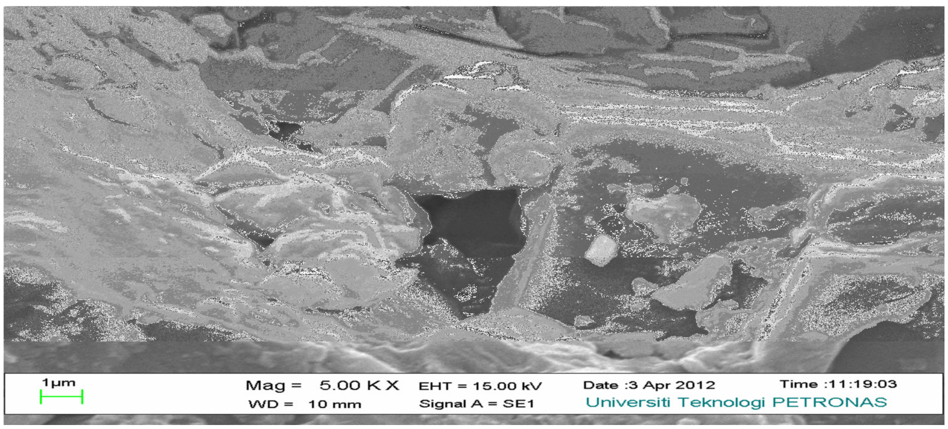

Figure 21: image from sample 3

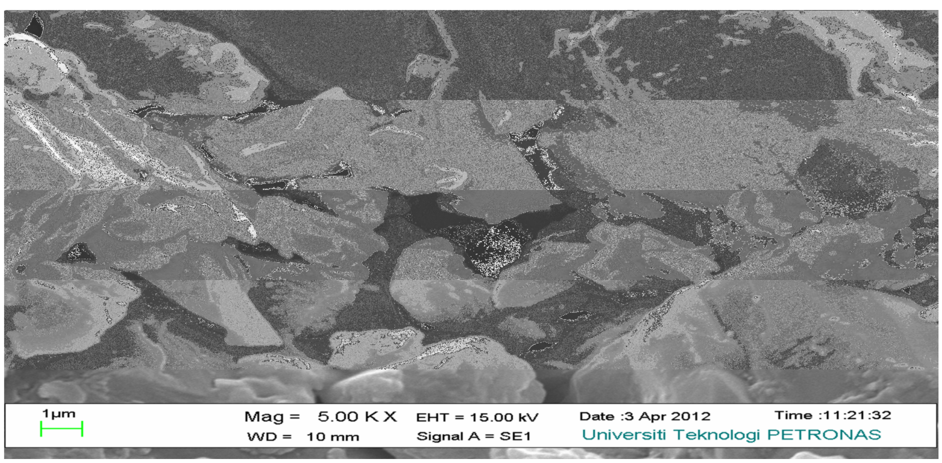

Figure 22: image from sample 5

Compact Anhedral

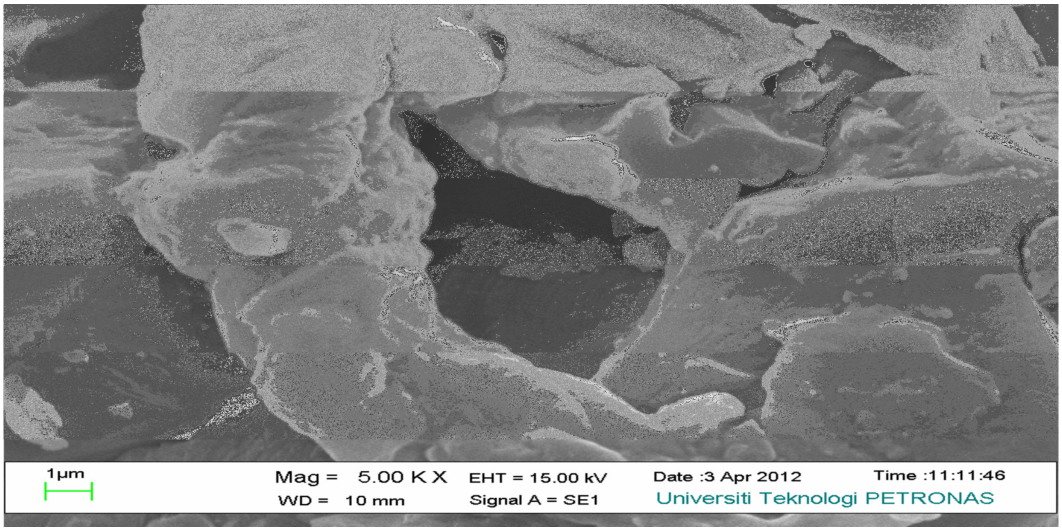

Figure 23: image from sample 4

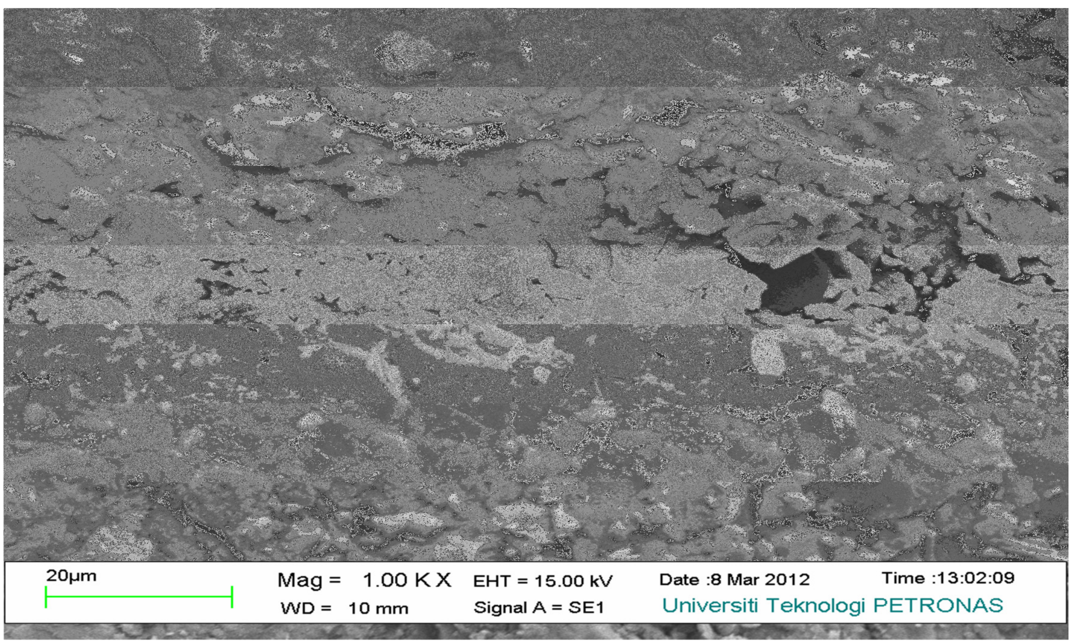

Figure 24: image from sample 2

5. CONCLUSION

From the data gathered during the timeline of this project, there are several conclusions that can be made.

1) The porosity and permeability of limestone in Gunung Kantan formation are very low.
2) There are two types of micrite that existed in limestone of Gunung Kantan which is micro rhombic polyhedral crystal and compact anhedral crystal.
3) Permeability of limestone increases with porosity.
4) The sonic velocity has an inverse relationship with porosity.

With these conclusion, the project have achieve the objective of determining the characteristic and petrophysical properties of Paleozoic limestone at Gunung Kantan, Sungai Siput with relation to pore type for possible correlation to other geophysical or seismic data.

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