THE RELATIONSHIP BETWEEN PORE SPACE AND GRAIN SIZE

BY

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PETROLEUM ENGINEERING

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BACHELOR OF ENGINEERING (HONS)

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UNIVERSITI TEKNOLOGI PETRONAS

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31750 TRONOH

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CERTIFICATION OF APPROVAL

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PETROLEUM ENGINEERING

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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 ORIGINALITY WORK CONTAINED HEREIN HAVE NOT BEEN UNDERTAKEN OR DONE BY UNSPECIFIED SOURCES OR PERSONS.

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MUHAMMAD RAIMI BIN JOHARI

ABSTRACT

The objective of this project was to study the relationship between pore space and grain size. Semanggol formation was selected to be the area of interest for this project. Semanggol formation has attracted several geologists to study the geological structure and the stratigraphical distribution. However, this project was focusing towards the rock properties such as porosity and permeability since these are the major interest in petroleum industry. Using the samples taken which consist of different rock types and grain size, several experiments were conducted and the result was compared. Several experiments were conducted; thin section analysis to analyze the grain size and sorting, Scanning Electron Microscopy (SEM) to visualize the pore space of the samples and the Mercury Pressure Porosimetry analysis to estimate several important variables including porosity and permeability. The results then were compared before the outcome of the project was finalized. Based on Guodong Jin, Carlos Torres-Verdin, and Chun Lan (2009), grain shape effects towards the pore space did exist. According to their research, bigger grain shape will decrease the porosity but at the same time increase the permeability. Based on these findings, the study was done towards the samples obtained to study the relationship between pore space and grain size.

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Within this opportunity, I would like to express my gratitude towards my supervisor, AP Askury Abd Kadir whose expertise, understanding, and patience, that has assist me a lot to complete my final year project.

Appreciation also to all the lab technologist and the trainee lecturer who help and gave ideas in completing this project. Although I faced many difficulties and obstacles in completing this project, with their help, I was able to seek a way out to proceed with the project.

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1.0 PROJECT BACKGROUND

Semanggol formation is located at the south of the Transect in Perak comprises black mudstone, sandstone, tuffaceous sandstone, tuff, paraconglomerate, siliceous shale and chert described as the Triassic sediments exposed. The chert contains radiolarians indicating late Early Permian to Middle Triassic of age. These rocks are generally thrusted northward and occupy the same orientation of fault planes. The excavation of rocks in the Semanggol Formation exposed more succession, making it feasible to study in detail the stratigraphical distribution of rocks, their age and relationship of conditions and properties in the formation. The study of grain size and pore space are very crucial in determining the potential of the formation to store fluid. These two factors need to be analyze in details to determine whether it will have effects on several important properties such as porosity and permeability.

1.1 Problem Statement

The Semanggol formation had been studied by several geologist by focusing their research on the age of the formation, the geological structure and the stratigraphical distribution. However, there are still many properties that have not been tested yet. For this project, grain size and pore space will be the main focus of study. The project will analyze the relationship between these two main criteria that may affect several important properties such as porosity and permeability. These properties are very important in analyzing the potential of existence of fluid, in this case the potential of water presence. Several samples with different grain size and pore space will be taken in different location at the same formation and will be compare to analyze the relationship between grain size and pore space.

1.2 Objectives

- Obtained samples from Semanggol formation with difference in rock type, grain size and sorting.
- To build core plugs from the sample taken to proceed with the experiment that need to be conducted.
- To analyze the effect of the grain size and pore space towards any other properties of the formation such as total porosity, effective porosity, and permeability.
- To determine the potential of fluid existence in the formation based on analysis done on the results of the experiments.

1.3 Scope of Work

- Samples were taken from Semanggol formation; analyze the geological structure and stratigraphical distribution of the formation.
- Samples taken were different in rock types, grain size, and grain sorting in order to able to compare the result of the experiments conducted to achieve the objective of the project.
- From the sample taken, several core plugs were made for the purpose of lab experiments in order to obtain several data and result.
- Several experiments conducted:

    1. CT Scan Analysis
    2. Mercury Pressure Porosimetry
    3. Scanning Electron Microscope (SEM)
    4. Thin Section Analysis

- From the results obtained from the experiments conducted, comparison of the results was done in order to determine the relationship between grain size and pore space existence.

2.0 THEORY AND LITERATURE REVIEW

The Semanggol Formation was introduced by Alexander (1959) for the sedimentary rock exposed in the Semanggol range in north Perak. The formation was probably deposited in the same basin, which was later separated into three areas by wrench faults which are in north Perak (Gunung Semanggol), south Kedah (Kulim-Baling) and north Kedah (Padang Terap). Burton (1973) then divided the formation into three which are chert member, rhythmite member and the conglomerate member, which later were called units by Teoh (1992). It were then interpreted to be in lateral and interfingering contact, representing lateral facies variation rather than in sequential superposition. The conglomerate was deposited in a proximal submarine fan, the rhythmite was deposited in distal submarine fan, and the chert was deposited in a basin environment (Ahmad Jantan et al., 1989). The chert also described as consisting of alternations of black, carbonaceous mudstone with chert, siltstone, and greywacke. The age of the Semanggol Formation was previously assigned as Triassic based on the occurence Bivalvia (Burton, 1973) and was later changed to Early Permian to Triassic (Basir Jasin, 1996, 1997).

The chert unit was considered as the oldest unit in Semanggol. The radiolarian bearing chert unit has been studied by many paleontologists (Sashida et al., 1992, 1993, 1995; Basir Jasin 1994, 1996, 1997; Metcalfe and Spiller 1994, Spiller and Metcalfe 1995a, 1995b, Spiller, 2002, and Basir Jasin et al., 2005a, 2005b). The discovery of Early Permian to Middle Triassic radiolarians suggests that the chert unit is not the oldest unit but it is partly interfingering with the rhythmite and the conglomerate units (Basir Jasin, 1997). Burton (1973) the described the chert unit as consisting of alternations of black, carbonaceous mudstone with chert, siltstone, and greywacke.

2.1 Chert

Chert is a microcrystalline or cryptocrystalline sedimentary rock material composed of silicon dioxide (SiO2). It occurs as nodules, concretionary masses and as layered deposits. Chert breaks with a conchoidal fracture, often producing very sharp edges.

Chert forms when microcrystals of silicon dioxide grow within soft sediments that will become limestone or chalk. In these sediments, enormous numbers of silicon dioxide microcrystals grow into irregularly shaped nodules of concretions as dissolved silica is transported to the formation site by the movement of ground water. If the nodules or concretions are numerous they can enlarge and merger with one another to form a continuous layer of chert within the sediment mass. Chert formed in this manner is a chemical sedimentary rock.

Some of the silicon dioxide in chert is thought to have a biological origin. In some oceans and shallow seas large numbers of diatoms and radiolarians live in the water. These organisms have a glassy silica skeleton. Some sponges also produce "spicules" that are composed of silica. When these organisms die their silica skeletons fall to the bottom, dissolve, recrystallize and might become part of a chert nodule or chert layer. Chert formed in this way could be considered a biological sedimentary rock.

The composition of chert is consist of microcrystalline silicon dioxide (SiO2). Chert has very few uses today. However, chert has two properties that made it especially useful:

- It breaks with a conchoidal fracture to form very sharp edges
- It is very hard (7 on the Mohs Scale)

The edges of broken chert are sharp and tend to retain their sharpness because chert is a very hard and very durable rock. Chert produces a spark when it is struck against steel (Geology.com).

2.2 Conglomerate

Conglomerate is a clastic sedimentary rock that contains large (greater than two milimeters in diameter) rounded clasts. The space between the clasts is generally filled with smaller particles and/or a chemical cement that binds the rock together. A clastic sedimentary rock can contain clasts of any rock material or weathering product that is washed downstream of down current. The rounded clasts of conglomerate can be mineral particles such as quartz or they can be sedimentary, metamorphic and igneous rock fragments. The matrix that binds the large clasts together can be a mixture of sand, mud, and chemical cement.

Conglomerate forms where a sediment of rounded clasts at least two milimeters in diameter accumulates. It takes a strong water current to transport particles this large. So the environment of deposition might be along a swiftly flowing stream or a beach with strong waves. The rounded shape of the clasts reveal that they were tumbled by running water of moving waves. Conglomerate often begins by being deposited as a sediment consisting mainly of small clasts. The finer size sand and clay which fill the spaces between the larger clasts is often deposited later on top of the large clasts and then sifts down between them to fill the interstitial spaces.

Conglomerate unable to break cleanly makes it a poor candidate for dimension stone and its variable composition makes it a rock of unreliable physical strength and durability. It can be crushed to make a fine aggregate that can be used where a low performance material is suitable. Analysis of conglomerate can sometimes be used as a prospecting tool. For example, most diamond deposits are hosted in kimberlite. If a conglomerate contains clasts of kimberlite then the source of that kimberlite must be somewhere upstream (Geology.com).

2.3 Rhythmite

A rhythmite consist of layers of sediment or sedimentary rock which are laid down with an obvious periodicity and regularity. They may be the result of annual processes such as seasonally varying deposits reflecting variations in the runoff cycle, the result of shorter term processes such as tides or the result of longer term processes such as periodic floods.

2.4 Pore space and grain size

To study the relationship between the pore space and grain size and the effect of it to several properties of the rock, understanding of the basic concept is very helpful in determining the action and further plans in analysing the Semanggol Formation.
Pore space is defined as the spaces within a rock body that are unoccupied by solid material. Pore spaces include spaces between grains, fractures, vesicles, and voids formed by dissolution. Pore space or also known as porosity consist of:

$$absolute\ porosity, Pt = \frac{(bulk\ volume - solid\ volume)}{bulk\ volume} \times 100$$

$$effective\ porosity, Pe = \frac{interconnected\ pore\ volume}{bulk\ volume} \times 100$$

There are two major types on how porosity is classified. Primary porosity is developed as the sediment is deposited and includes inter and intra particle porosity where as secondary porosity develops during diagenesis by dissolution and dolomitization, and through tectonic movements producing fractures in the rock.

Primary porosity in sandstones is principally interparticle porosity, dependent on the textural maturity of the sediment, controlled largely by depositional processes and environments, and to a lesser extent on compositional maturity.

Grain size refers to the physical dimensions of particles of rock or other solid. It can be range from very small colloidal particles, through clay, silt, sand, and gravel, to boulders. Size ranges define limits of classes that are given names in the Wentworth scale used in the United States. The Krumbein *phi*(φ) scale, created by W.C. Krumbein is logarithmic and computed by equations and shown at the appendices.

Pore space and grain size play very important role in determining the geological properties of the formation. These two factors are believe to effect some of the properties of rock such as the rock strength, porosity and permeability.

In general, the primary porosity increases as the grain size increases, the sediment is better sorted and more loosely packed, the grains become better rounded, and the clay content decreases (Tucker, 2001).

A research has been on pore-level study of grain shape effects on petrophysical properties of porous media indicate that although it is widely accepted that grain anisotropy can affect physical and petrophysical properties of porous media, the exact relationship is not well understood because of the difficulty of separating grain shape effecs from those due to other external properties of clastic rocks, such as grain size, sorting, roundness, and packing (Guodong Jin, 2009). Surface morphology of natural clastic sediments is dependent on five textural properties; grain sizes, sorting, shape, roundness, and packing (Fraser, 1935; Beard and Weyl, 1973). For example, poorly sorted grains generally have closer packing and lower porosity across a wide range of grain sizes, as fine grains tend to fill the void space between large grains. Well rounded grains with high sphericity should pack with a minimum of pore space (Beard and Weyl, 1973).

In general, sedimentary rocks form by deposition of grains followed by compaction and cementation. The last two processes determine the final pore space geometry and connectivity. Compactions occurs as the weight of the overlying layers increases. It forces the grains to move closer together, hence reducing pore space and pressing out some of the contained air and water (Figure 2.4.1) (Guodong Jin, 2009).

Four models of grain packs were constructed with same grain size but different aspect ratios. The grain size is defined as the length of the shortest axis of a grain, while the aspect ratio is defined as the ratio of the length of the longest axis of a grain to that of its shortest axis. The four computer-generated random grain packs with the same grain size Rb=0.1mm but different aspect ratios Ra/Rb=1.0, 1.5, 2.0, 2.5 respectively(Figure 2.4.2). uniform grains are randomly placed, and went through the rock formation processes. In summary, the result shown that the spherical grain pack exhibit a higher porosity compared to ellipsoidal grain packs (Figure 2.4.3). The effect of also shown in average permeability calculation where the spherical grain pack exhibit lower permeability (Figure 2.4.4)(Guodong Jin, 2009).

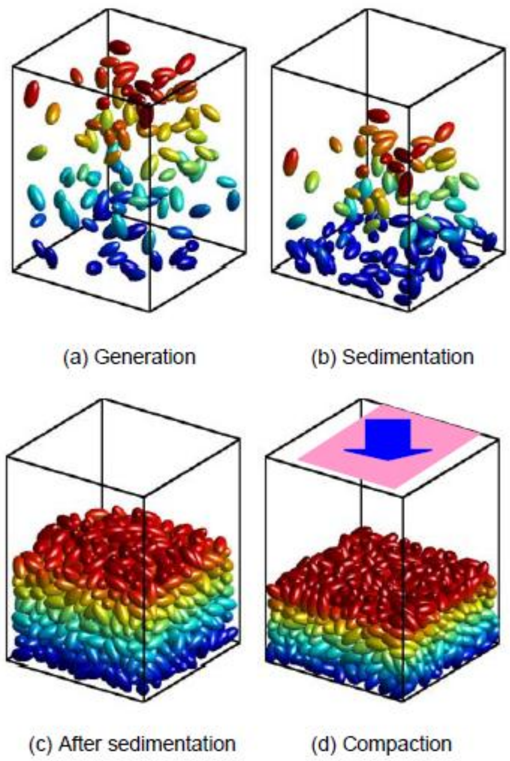

Figure 1: Schematic diagram of the rock formation processes in the simulation

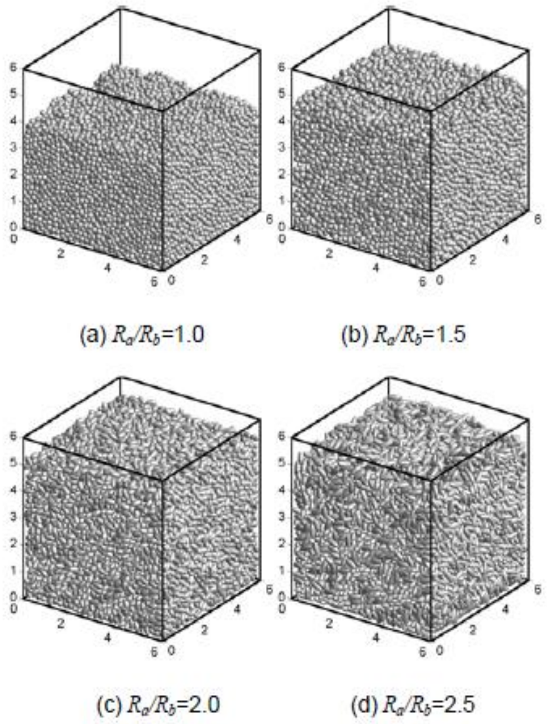

Figure 2: Grain packs obtained after simulation of gravity sedimentation for the grain packs

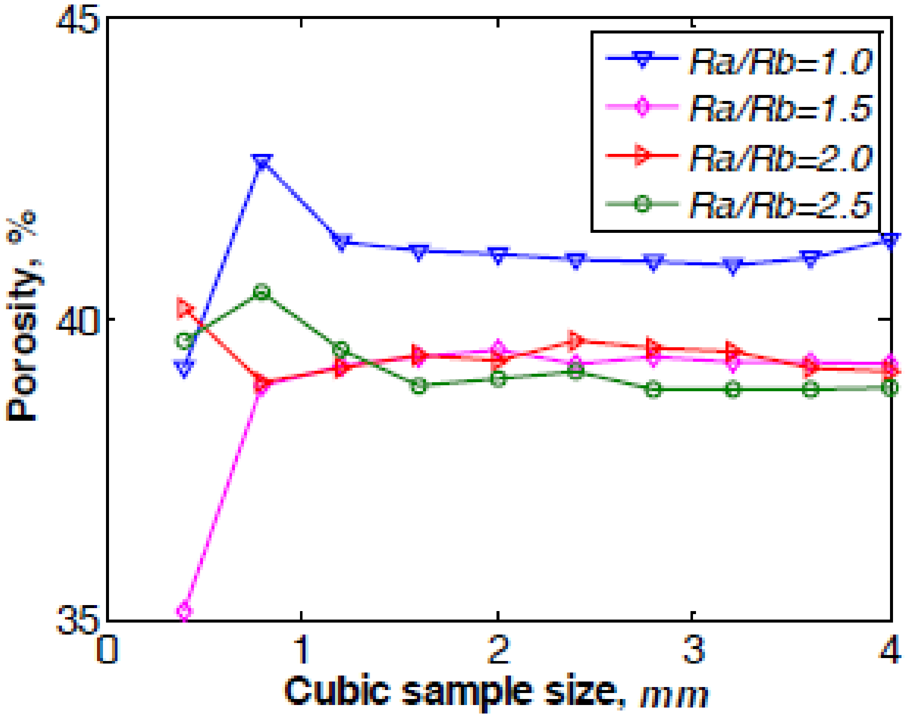

Figure 3: Variations of porosity with cubic sample size for the four grain packs

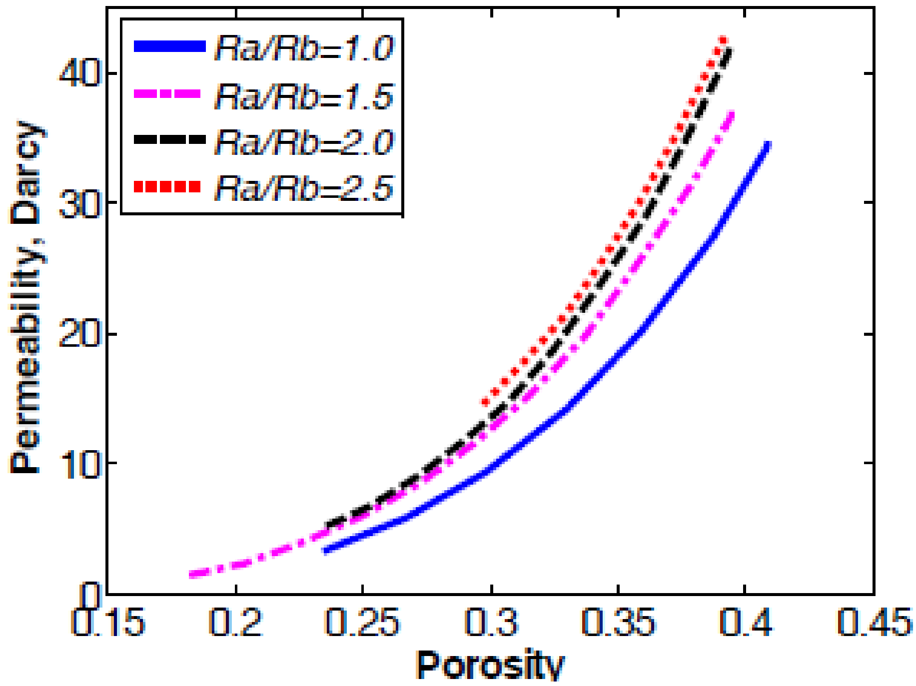

Figure 4: Variations of average permeability with porosity of the four grain packs

3.0 METHODOLOGY

3.1 The study on Semanggol Formation

Before begin any project regarding the Semanggol formation, the first step taken was to analyze the previous research done on this formation by other researchers. This will help in further understanding of the Semanggol formation and deciding the objective or the target of this project. Papers written regarding the formation for several researchers such as Basir Jasin and Zaiton Harun (2007) were used as a based in understanding about the formation. For the project itself, Guodong Jin et. al. provided details explaination regarding the project they had done which is similar to this project; the study of grain size and pore space relationship.

3.2 Obtaining Samples from Semanggol Formation

From the recent field trip done to collect samples at Semanggol formation (N 04° 57' 21.5", E100° 40' 02.4"), the current structure of the formation containing very hard rock structure and makes it difficult for the samples to be obtained. Hence, samples were obtained from the existing rock samples which were already fall into pieces due to nature activity. The total of 8 samples with different type of rock and grain size and sorting will be used as the basis of this project. The samples will be used to verify the geological structure and other properties before being cut into several core plugs for further lab test.

3.3 Lab Experiment for Analysis of the Properties

Several tests were conducted at the UTP lab since the lab is equipped with advance equipments:

i. CT Scan Analysis

   Computed Tomography (CT) scanning allows observations and measurements to be extended into three dimensions. The data can be visualized to observe the textural relationships among phases and structures. CT scan also allows imaging and quantification of three-dimensional void structure in solid rocks and soils, which improve the understanding and characterization of the way fluids reside in and move through the subsurface. Pores and fractures larger than a few microns can be imaged directly, and void space at all scales can be measured by scanning samples in varying conditions of saturation. Such analyses can reveal the varying ways in which porosity is hosted by different rock components, and enable estimation of direction and degree of flow anisotropy.

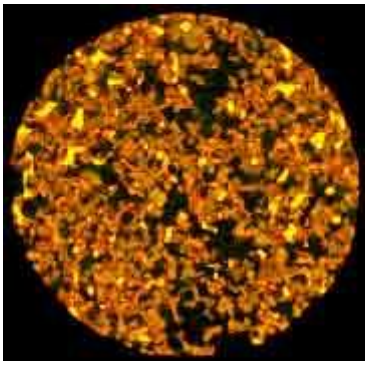

Figure 5: Sandstone Porosity, Single Slice and 3D recon

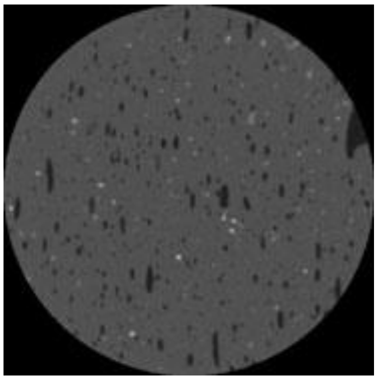

Figure 6: Porosity measurements

The experiment was done by Ketcham, R.A. and Iturrino, G.J. (2005) using the CT scan for each samples to see the partial porosity. The image on the left is a single representative CT slice, with gray level corresponding to X-ray linear attenuation coefficient, a function of density and atomic number. The right side images are maps of partial porosity, in which lighter shades of gray indicate higher porosity.

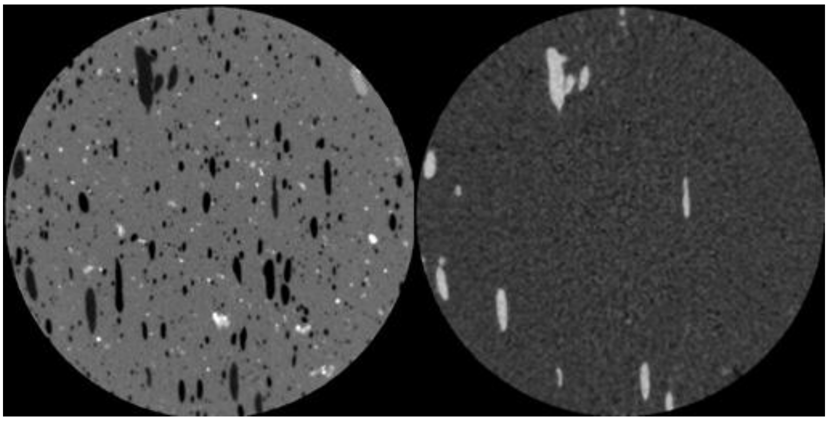

Figure 7: Example of samples taken by Ketcham and Iturrino on the indication of porosity using CT scan

The CT scan provides imaging data that can be used for computer simulations, economic evaluations, and site characterizations. The scanner generates a three-dimensional (3-D) image of an object's structure by collecting and combining many 2-D X-ray images. Coal, rock, and other geological samples are imaged to measure how liquids, gases, and solids flow through them, or to measure other rock-fluid phenomena, such as how CO_2 is absorbed of adsorbed in coal cores. The measurement provides information on the actual distribution of minerals and fluids inside samples, rather than providing merely average measurements.

ii. Mercury Pressure Porosimetry

In order to analyze the relationship between grain size and pore space, several measurements that need to be done are the porosity and permeability which are very crucial in determining the potential reserves of the formation. In order to do that, samples obtained from the Semanggol formation will be tested in Mercury Pressure Porosimetry. It consist of two major equipment which are PASCAL 140 and PASCAL 240.

PASCAL 140 is an automatic instrument for sample preparation for porosimetric analysis, and to measure porosity in the ultramacro and macropore regions. It allows measurement on the volume and size of macropores and mesopores in solid substances.

PASCAL 240 is used for the determination of pore size and volume, in the range 3.7 and 7500 nm of radius, by means of mercury intrusion at high pressure up to 200 MPa compare to the PASCAL 140 which apply 400kPa maximum.

The technique is based on the mercury property to behave as non-wetting liquid with a lot of solid materials which enable penetration through the open pores of a solid sample under the effect of increasing pressure using the Washburn Equation by taking some assumptions into considerations:

1. The mercury surface tension and contact angle with the solid material are constant during the analysis.
2. The intrusion pressure must be on equilibrium.
3. Pores are considered as being of cylindrical shape.
4. Solids are not subject to deformation under the effect of pressure.

By measuring the quantity of mercury penetrated into the sample pores and the equilibrium pressure at which intrusion occurs, experimental data are obtained to calculate the pore volume distribution as a function of their radius.

iii. Thin Section Analysis

A thin section analysis provides an unbiased estimate of areal composition of the surface measured. A randomly chosen area provides and unbiased estimate of composition by volume. Orientation of the rock or of the thin section with regard to some structure element of the rock may improve or reduce the efficiency of sampling but will not in itself bias the result (Chayes, 1949).

Thin section preparation helps in examine the samples microscopically in order to analyse the characteristics of the soil or rock. This analysis is carried out using transmitted polarised light,

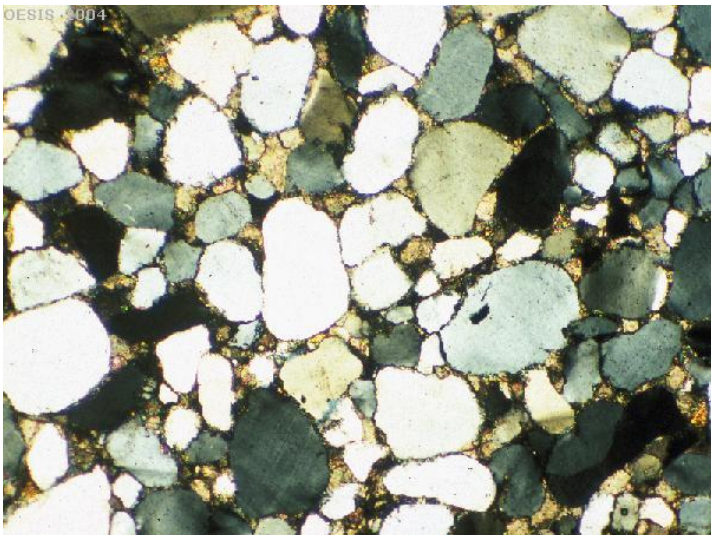

Figure 8: Example of samples taken by Ketcham and Iturrino on the indication of porosity using CT scan

which only provide efficient result when the samples is made at the exact thickness. Reflected light also can be used for certain applications and this technique requires the samples to have flat surface and highly polished to achieve the best results. The usage of electron microscopes also contributes for top quality thin section of wide range of materials.

To produce a very high quality thin section, this takes time and highly skilled process was done by hand. Based on the samples taken, the first step taken is the trim the bulk material down to dimensions suitable for slide mounting. A slice should be cut and trimmed to fit the slide. The specimens are then bonded to the glass slides using the epoxy resin. It is then being spread on the dried on the flat slide and the samples is placed on top of it after the bubbles has been eliminated to ensure even loads and parallel bonding. Then, the thick chips are trimmed down to a thickness of 30 µm, or 40 µm if the section is to be polished.

3.4 Analysis of the Results Obtained from experiments

From the SEM, structures of the rock samples can be determine and analyze. Hence, from this experiment, we could estimate the grain sorting and pore space present in that formation.

From the Mercury Pressure Porosimetry analysis, the result will be the main concern of the study. The measurements especially porosity and permeability will determine the result of the study. With the grain size estimation obtained from thin section analysis, the relationship of pore space and grain size able to be determined.

3.5 Gantt Chart

ACTIVITIES	WEEKS																
	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16
Project work commences								Mid Semester Break									
Briefing & update on students progress																	
Preparation of Progress Report																	
Submission of Progress Report																	
Project work commences																	
Preparation for Pre-EDX																	
Pre-EDX(poster presentation)																	
EDX and final report submission																	
Preparation for final presentation																	
Final oral presentation																	
Submission of hardbound copies																	

4.0 RESULT AND DISCUSSION

From the total of 8 samples collected from Semanggol, 4 samples were selected to be analyze in details since it represent different grain size which are conglomerate 1(C1), fine sandstone (S1), conglomerate 2(C2), and coarse sandstone (S2).

4.1 Mercury Pressure Porosimetry

From the Mercury Pressure Porosimetry test, results obtained as shown:

	C1	S1	C2	S2
Sample mass(g)	1.56	0.82	1.25	1.47
Density(g/cm³)	2.67	2.56	2.66	2.45
Bulk density(g/cm³)	2.4781	2.0395	2.2027	2.4992
Void volume (mm³/g)	30.43	102.85	79.31	1.34
Accessible Porosity (%)	5.71	14.58	8.37	16.6
Inaccessible Porosity (%)	1.8	6.26	9.05	-16.27
Total pore volume(mm³/g)	10.41	37.65	38.09	67.96
Total pore space area(m²/g)	2.011	3.211	9.583	5.089
Average pore diameter (nm)	20.71	46.9	15.9	53.42
Max pore diameter(nm)	25.6	58.11	10.93	12.73
Median pore diameter(nm)	18.55	58.53	15.67	211.89
General permeability (md)	0.00031299	0.004893	0.00061903	1.4495

Table 1: Mercury Pressure Porosimetry results

4.2 Scanning Electron Microscopy (SEM)

1. Conglomerate 1(C1)

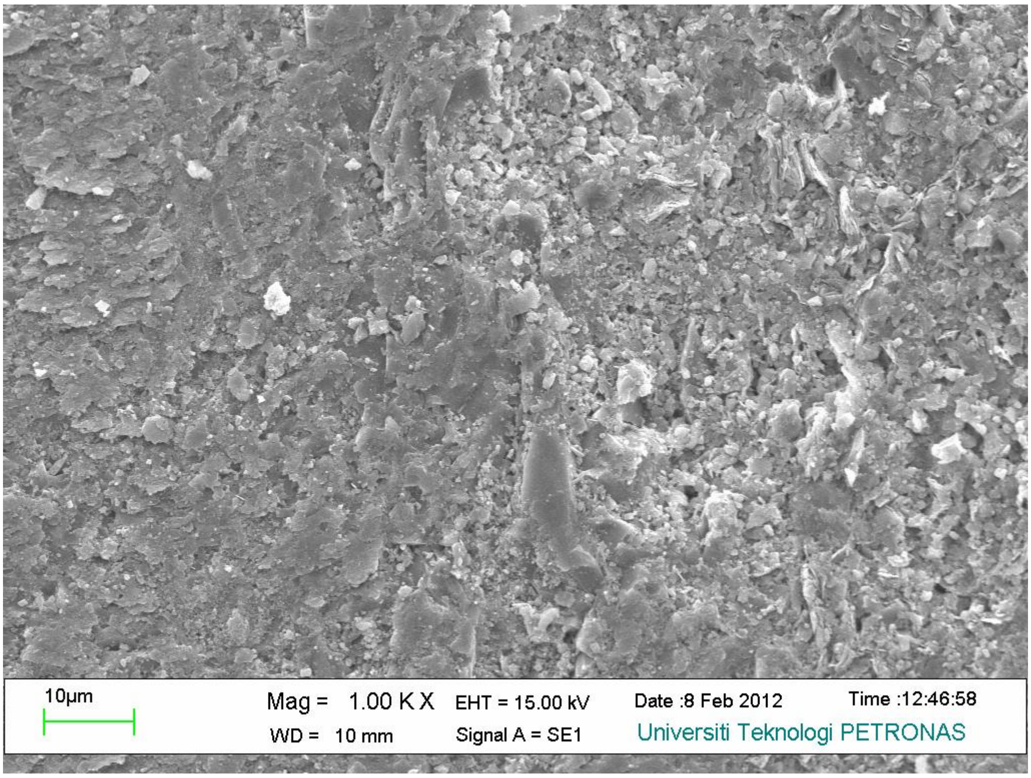

Figure 9: C1 image with 1000 magnification using SEM.
Grain are visible and sorted well. Pore hardly visible any pore space

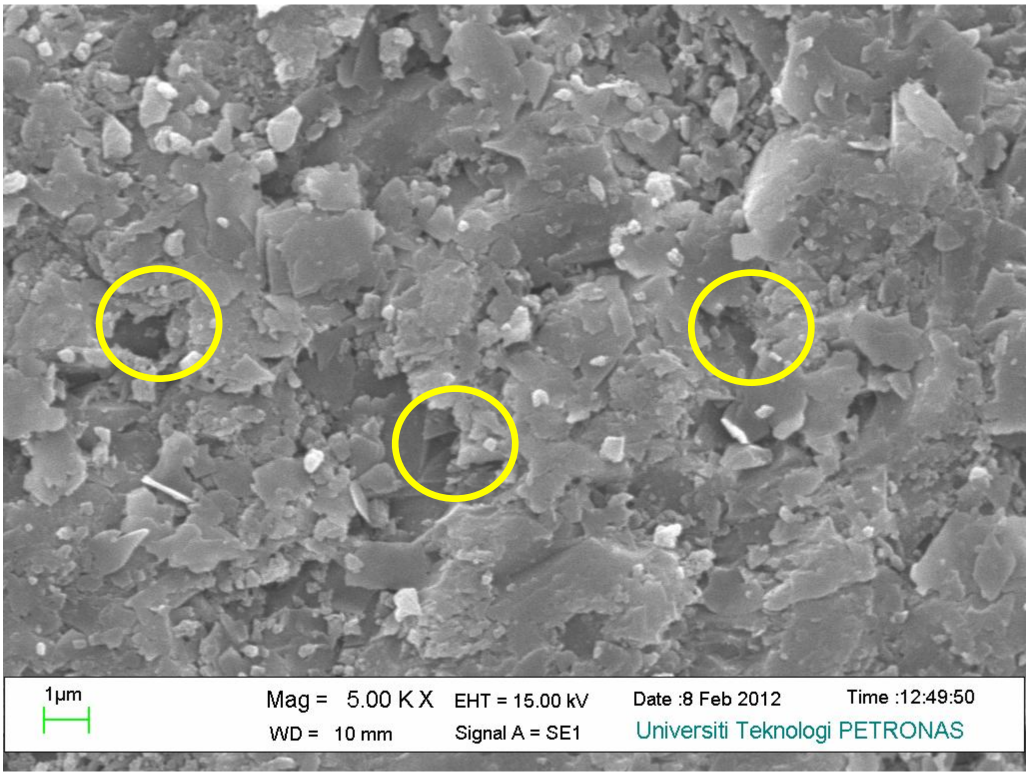

Figure 10: C1 image with 5000 magnification using SEM.
Pore are visible (yellow circle) but the total pore is not effective as reservoir prospect

2. Fine sandstone (S1)

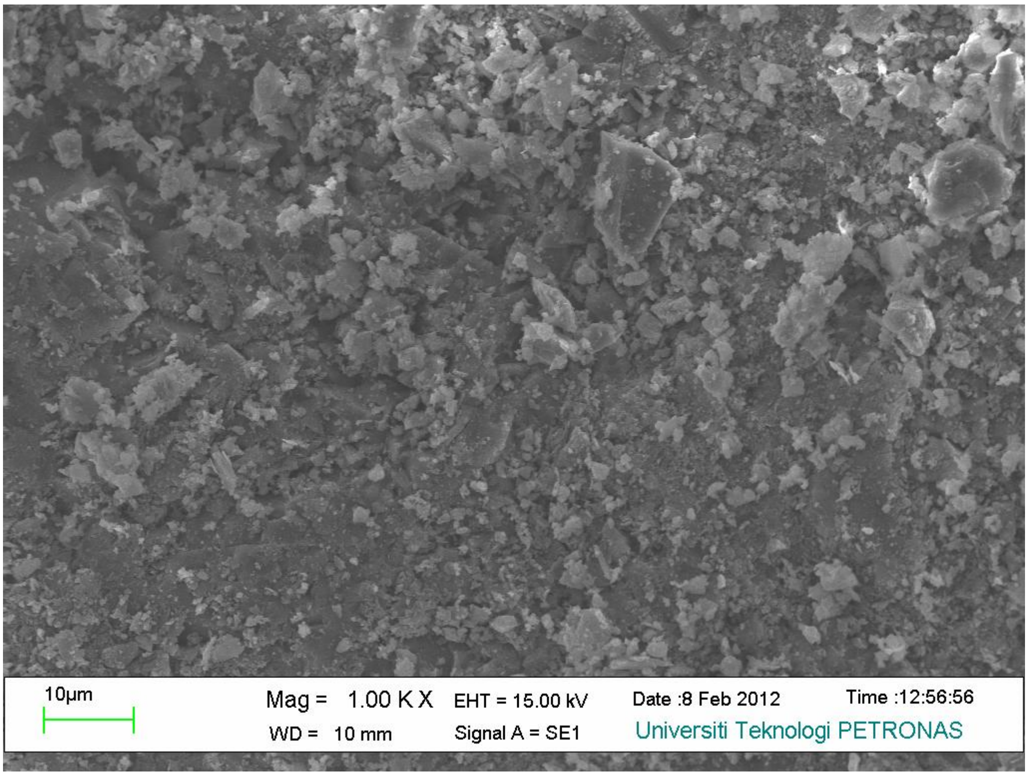

Figure 11: S1 image with 1000 magnification using SEM.
Grain and pore are visible due to grain sorting

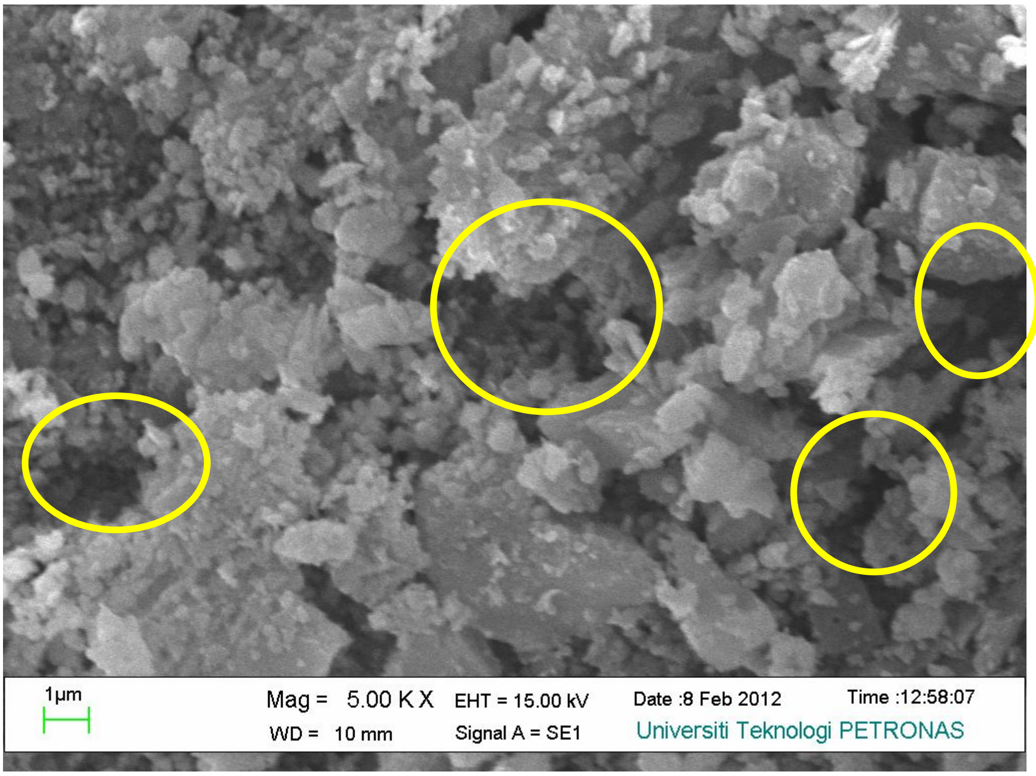

Figure 12: S1 image with 5000 magnification using SEM.
Pores are visible (yellow circle) and can be considered as reservoir prospect due to high pore volume

3. Conglomerate 2 (C2)

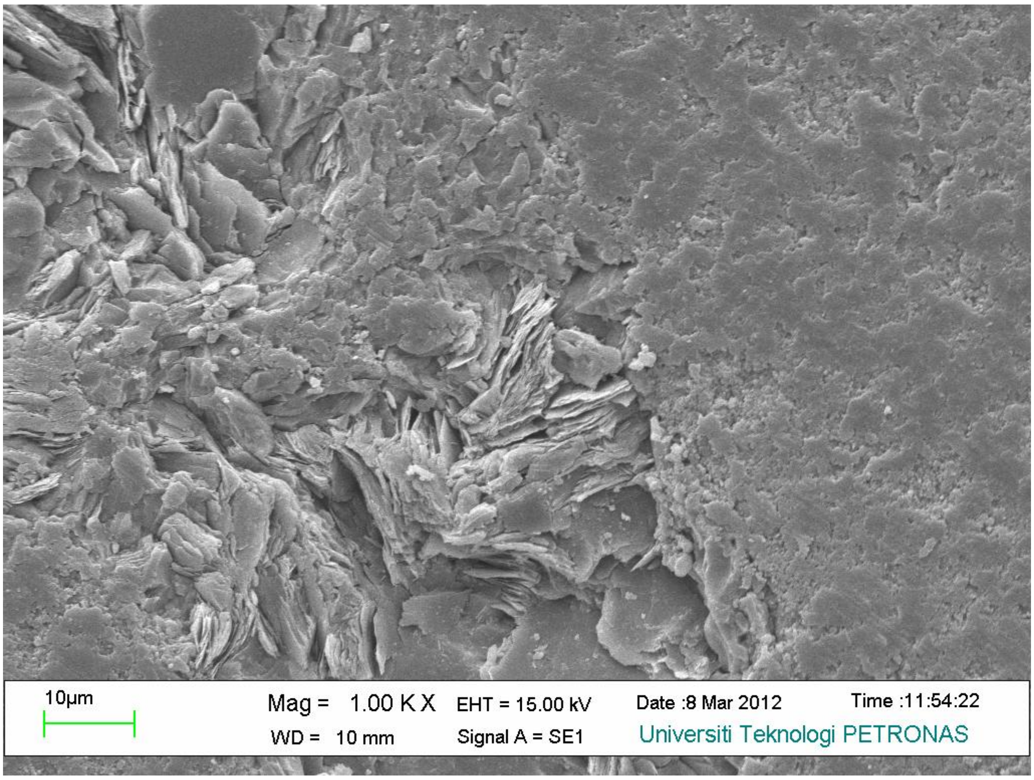

Figure 13: C2 image with 1000 magnification using SEM.
Grain is visible but no pore can be seen

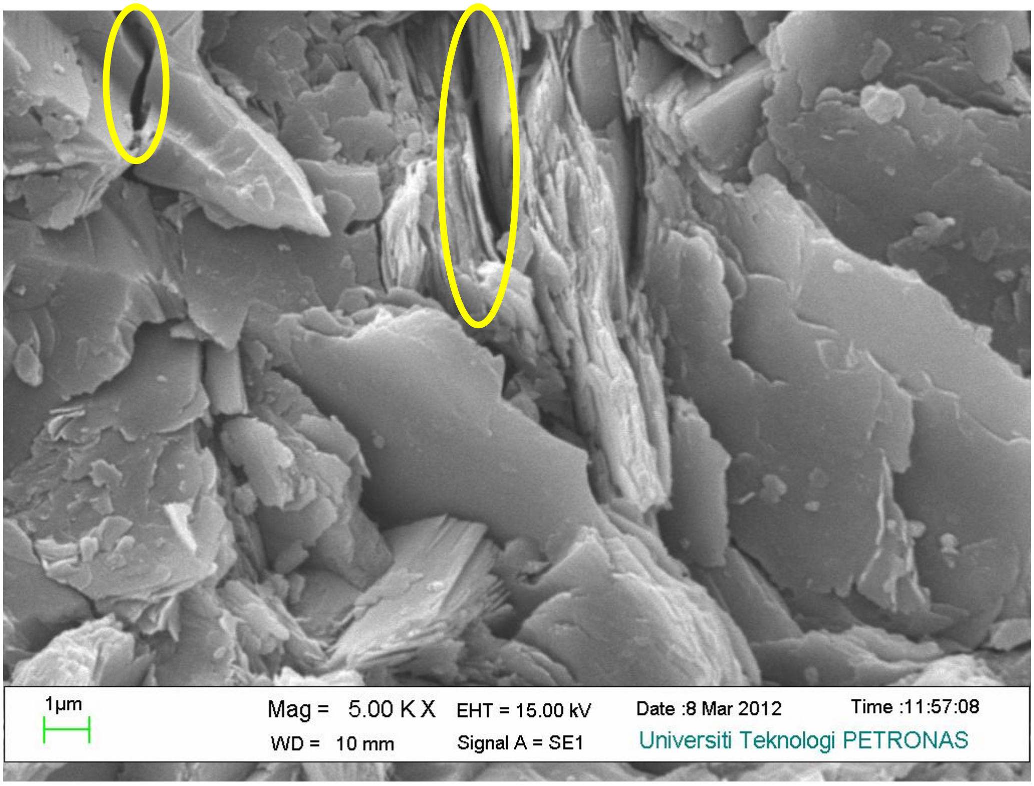

Figure 14: C2 image with 5000 magnification using SEM.
Grain is visible and well sorted. Only small pore detected (yellow circle) which indicate small pore volume

4. Coarse sandstone (S2)

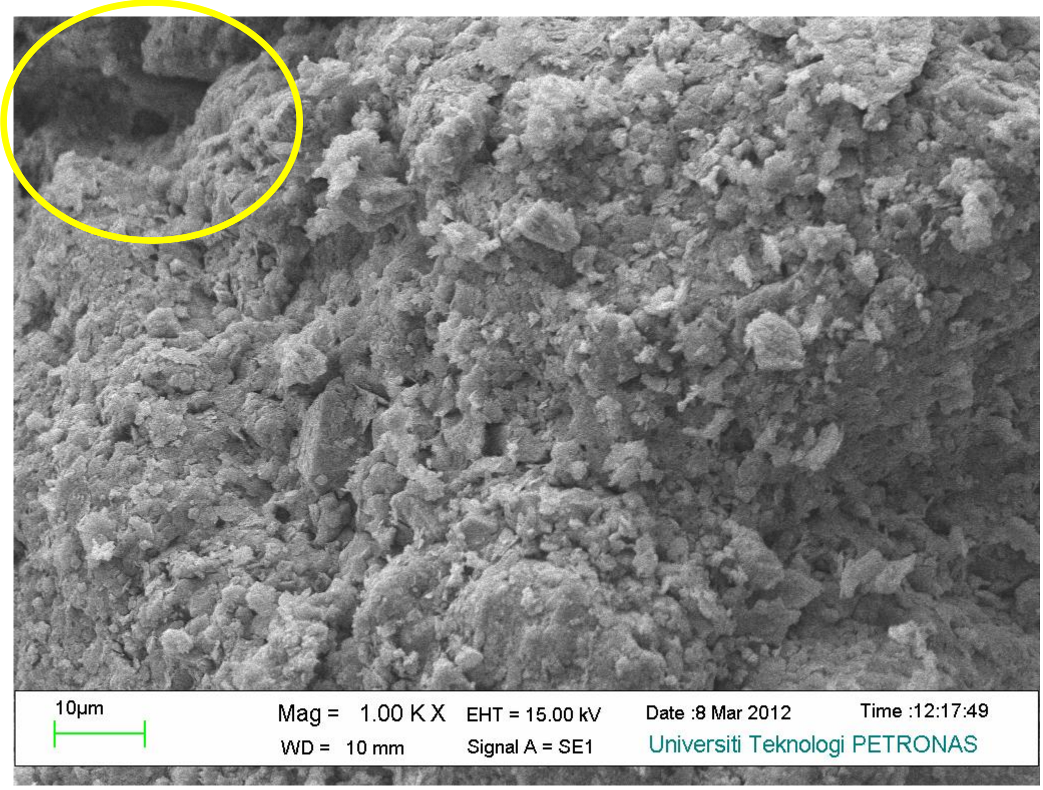

Figure 15: S2 image with 1000 magnification using SEM.
Grain is visible and not well sorted. Many potential pore detected (yellow circle) indicate the sample has the potential as reservoir prospect

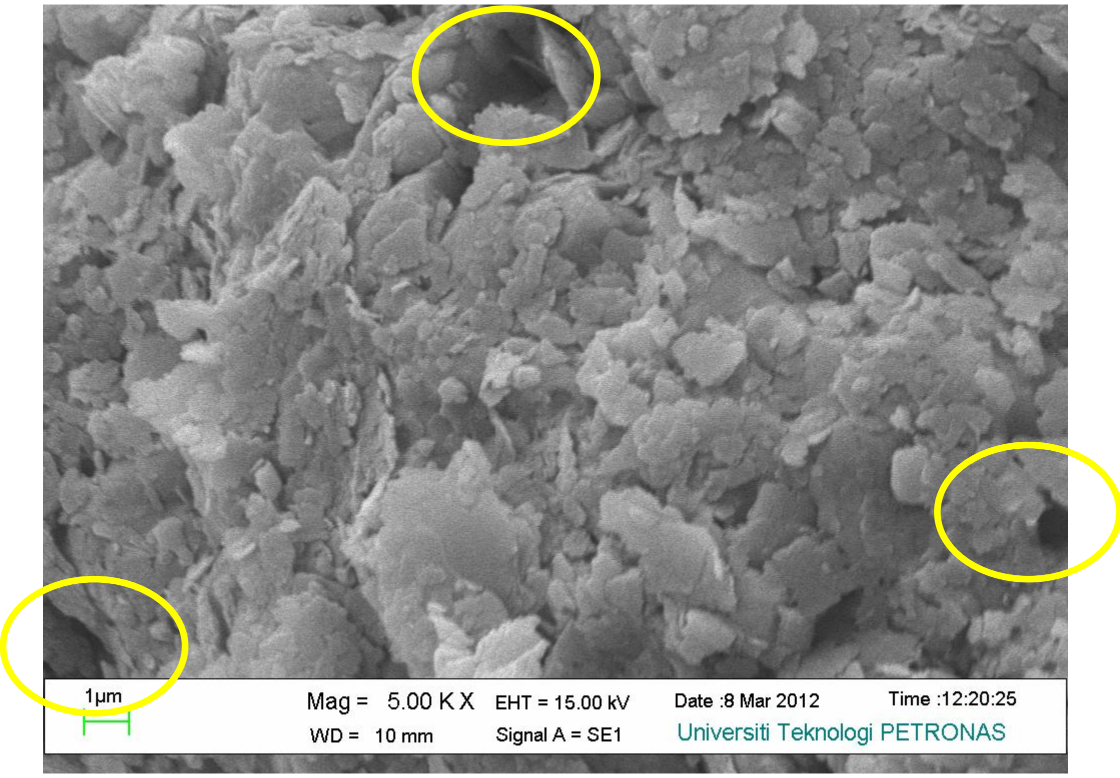

Figure 16: S2 image with 5000 magnification using SEM.
Pore can clearly be seen.

From the results obtained from these two experiments, analyses were done for each sample.

For conglomerate 1 (C1), the SEM shown that the grain size for this sample is poorly sorted. Due to the size of the grain which can be considered small and poorly sorted, hence pore space can hardly visible with bare eyes. Therefore, estimation could be made that this sample contained less pore space due to the grain size and sorting. For that reason, this type of rock is not suitable or hardly could be recognized as reservoir prospect whether to contain oil and gas or in this case where the sample is taken, contained water.

Samples for fine sandstone (S1) shown that the grain size is not as compact compared to the C1 sample. However, since the size of the grain is quite small, some part of the sample contained less pore space but generally this sample shown that this type of rock is well sorted, more brittle, which could be estimated to have lots of pore space. Therefore, fine sandstone can be considered as reservoir prospect.

As shown by the SEM, conglomerate 2 (C2) is very poorly sorted with the large grain size. However, since the grain size is bigger than the C1 sample, neglecting the effect of sedimentation and compaction, it should have more pore space compare to C1 since it cannot fit into small space left between grains. Even though this sample have more pore space, the SEM hardly shown any pore space which can be estimate that the pore space are not connected to each other. Hence, this type of rock hardly could be consider as reservoir prospect.

For the last sample which is coarse sandstone (S2), SEM shown large grain size with a lot of pore space visible. Large grain size also leave many pores due to the grain cannot fill the empty spaces created during the sedimentation process. The structure of the sample also indicate that this sample is very brittle due to many pores connected to each other which shown that this type of rock is considered as reservoir prospect.

4.3 Thin Section Analysis

Depending on the result of the SEM only does not help in determining the grain size. Using thin section analysis and J Micro Vision software, the grain size was estimated for the samples.

Figure 17: Minerals identification

Using the microscope provided in the SEACARL lab in UTP, with high resolution microscope, the image produced are easier to interpret. For every sample, 3 pictures were took; grey colour intensity which is needed in order to run the image in the J Micro Vision software, colour with higher and lower interference to differentiate the minerals in the samples.

To differentiate the minerals in the samples, guideline of colour of the minerals can be followed. For Semanggol, from the thin section analysis made, quartz is the majority minerals present in conglomerate and sandstone samples. This colour can be seen while comparing the changes of colour interference in the samples as shown for every samples. However, the thin section made has to be thin enough by following the recommended thickness to be able to see this criteria. Even though the samples prepared were not thin enough to totally decide the minerals present which were shown by the grains with purple in colour (can be seen as purple in colour with big size), most of the part of the thin section changed it colours representing the minerals present in the samples.

The next picture taken was the grey colour (transparent) to be used in the J Micro Vision. This software is able to differentiate the intensity threshold to differentiate the grain and the matrix since the grey intensity are different. Using this software, errors in estimating the grain size could be made since it is manually operated to select the border of the colour intensity to be selected as grain. However, based on the length and wide plot from this software estimation of the grain size, the grain size should be on the range of the graph plotted and the size where the most point is present.

1. Conglomerate 1 (C1)

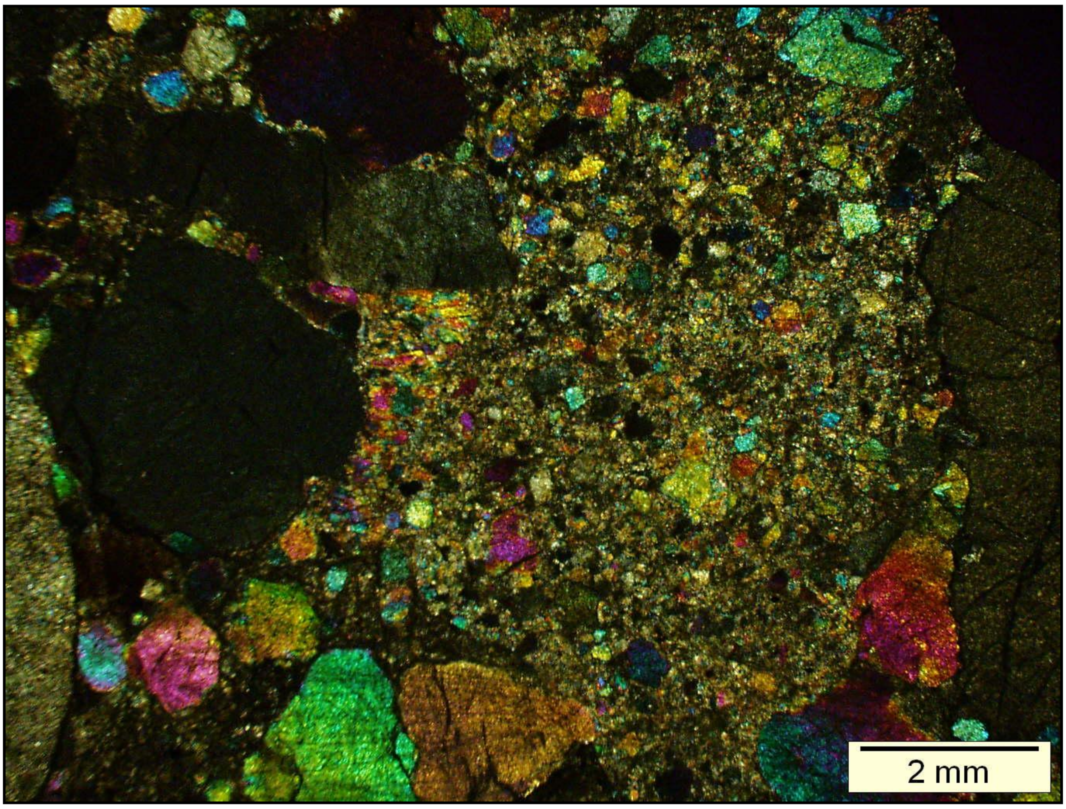

Figure 18: C1 image with high colour intensity

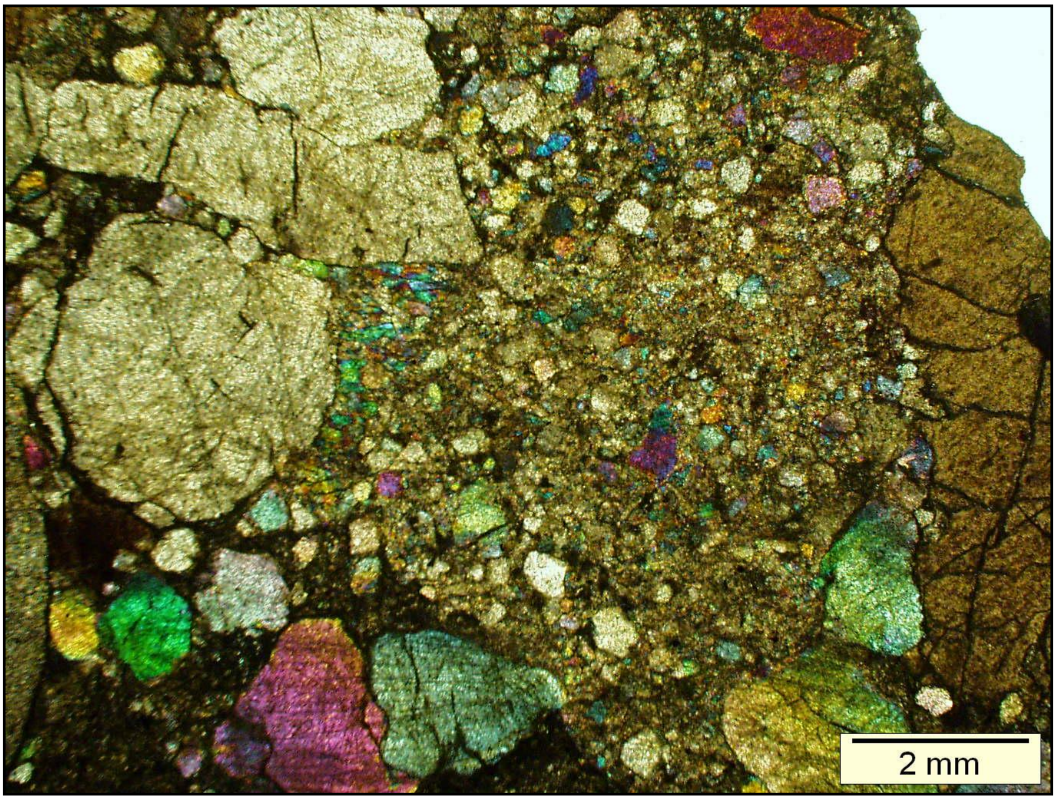

Figure 19: C1 image with low colour intensity

2. Fine Sandstone (S1)

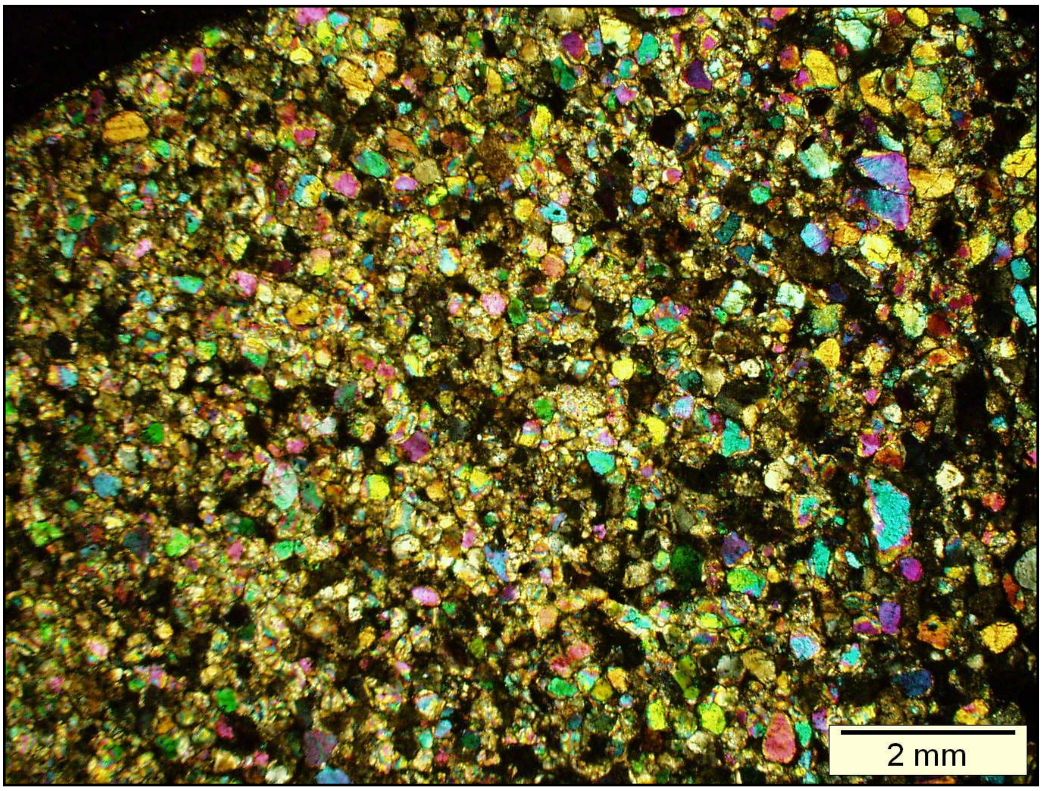

Figure 20: S1 image with high colour intensity

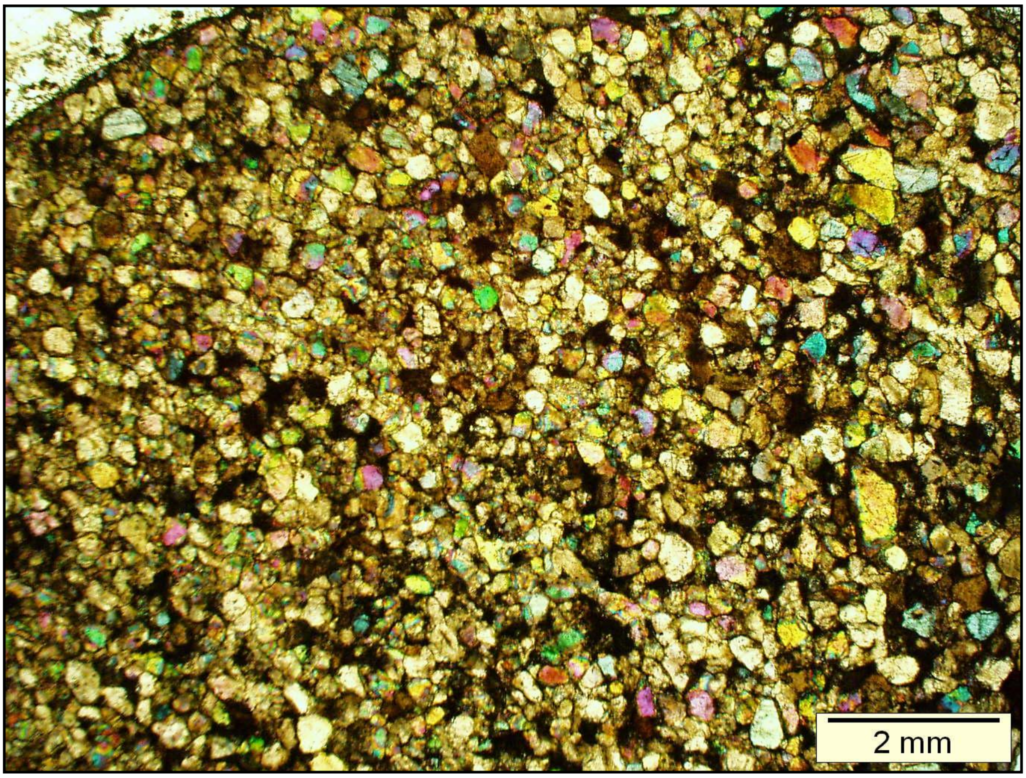

Figure 21: S1 image with low colour intensity

3. Conglomerate 2 (C2)

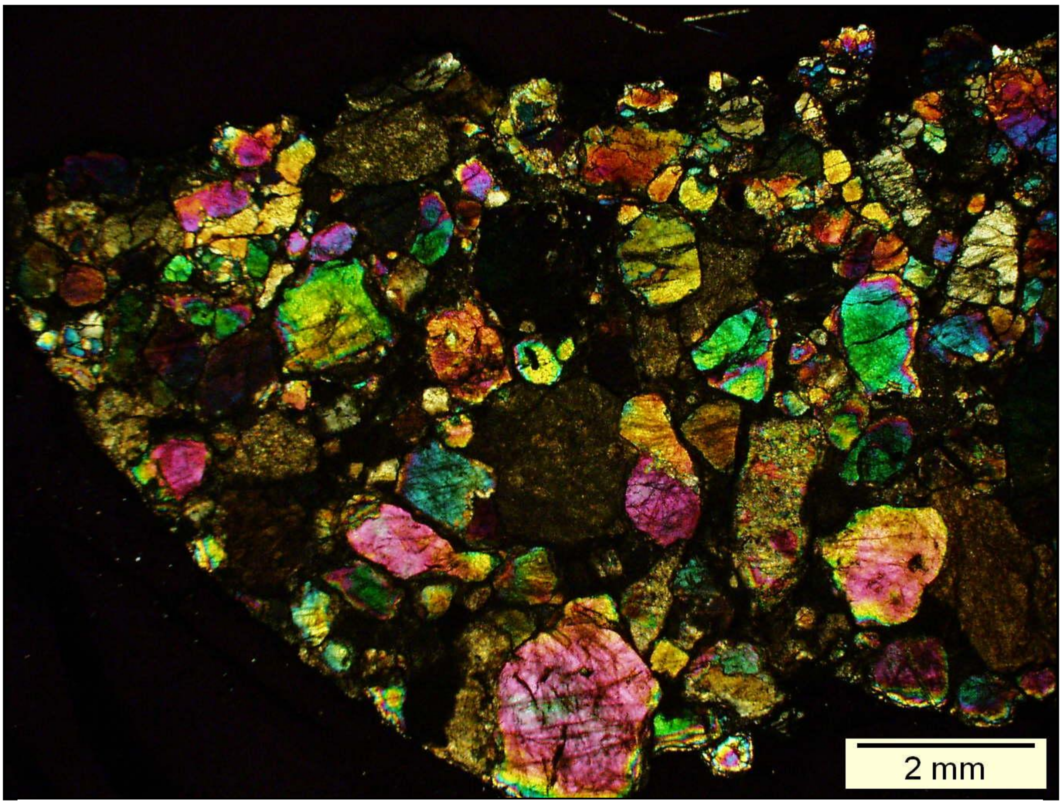

Figure 22: C2 image with high colour intensity

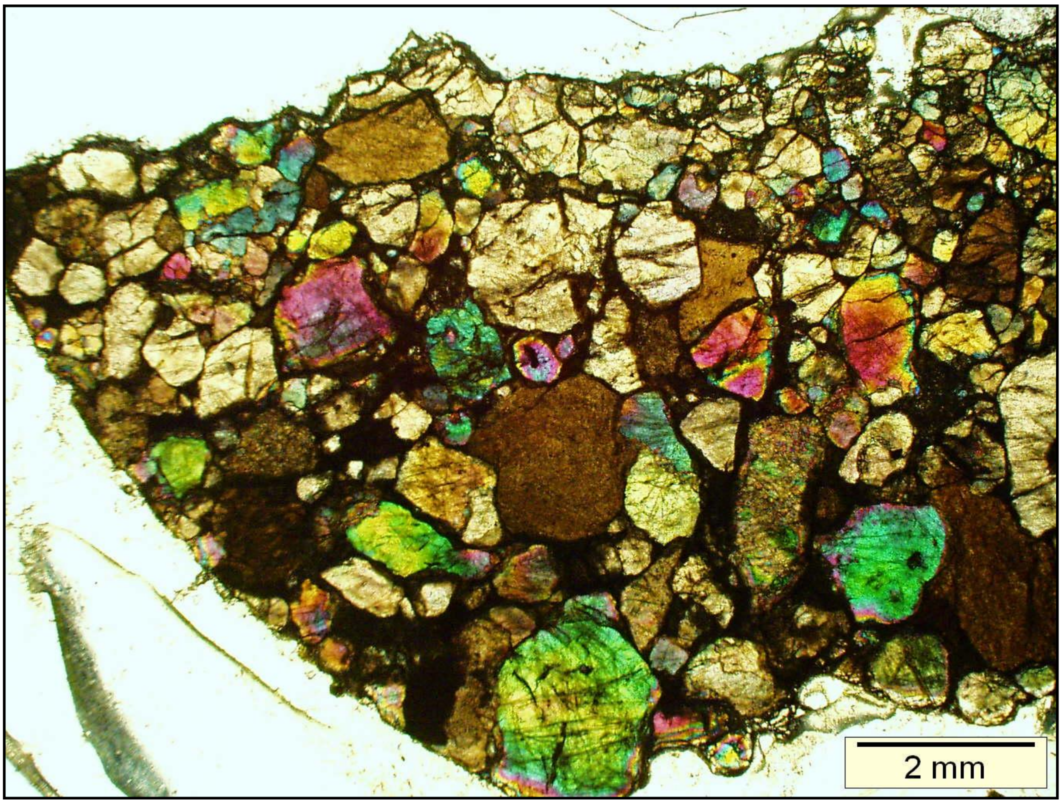

Figure 23: C2 image with low colour intensity

4. Coarse Sandstone (S2)

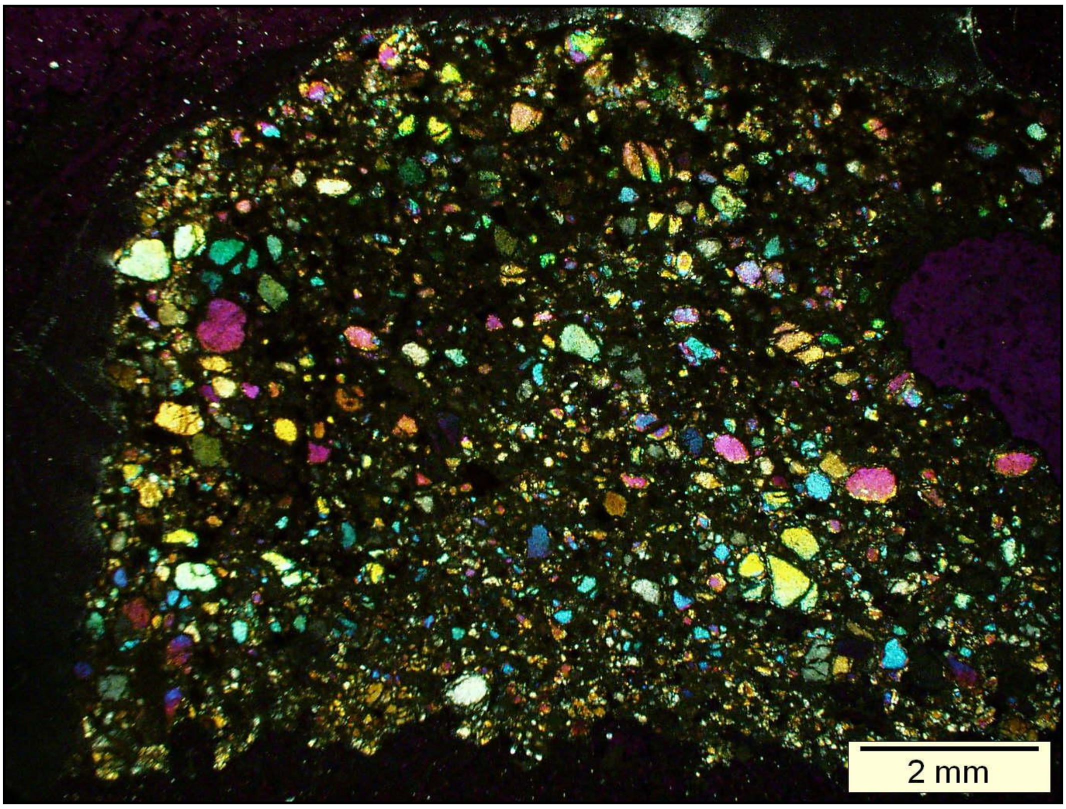

Figure 24: S2 image with high colour intensity

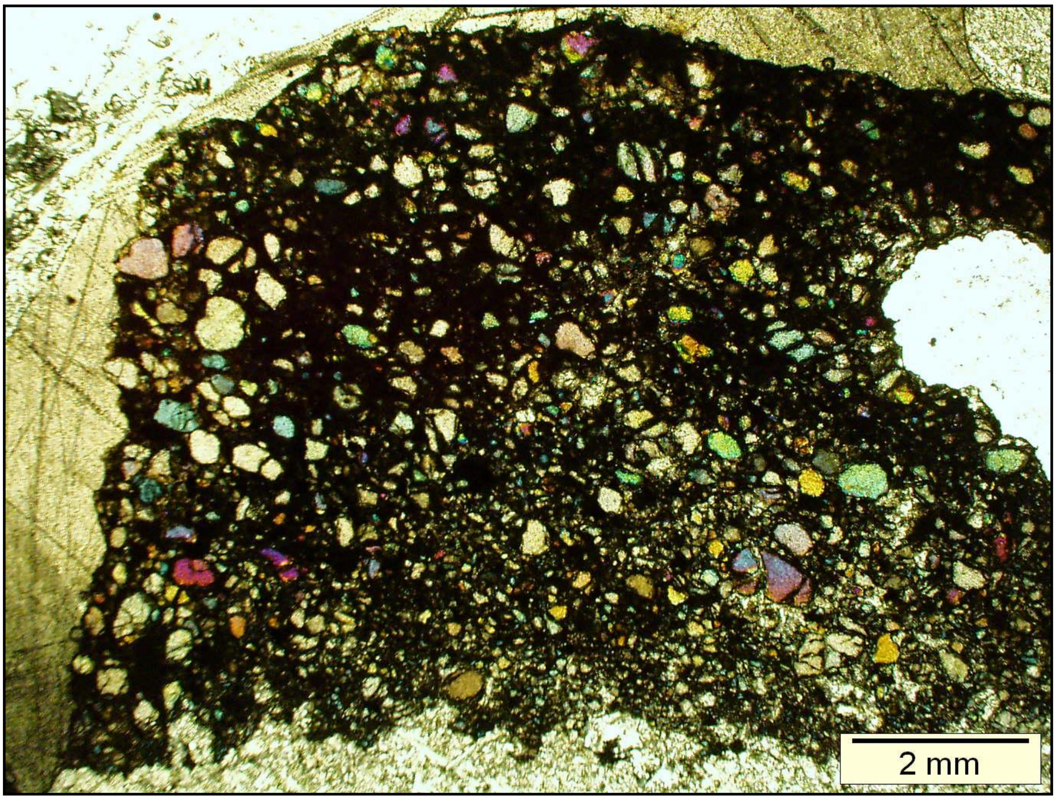

Figure 25: S2 image with low colour intensity

4.4 J Micro Vision

Using the J Micro Vision to estimate the grain size (red colour indicates the grain selected):

1. Conglomerate 1 (C1)

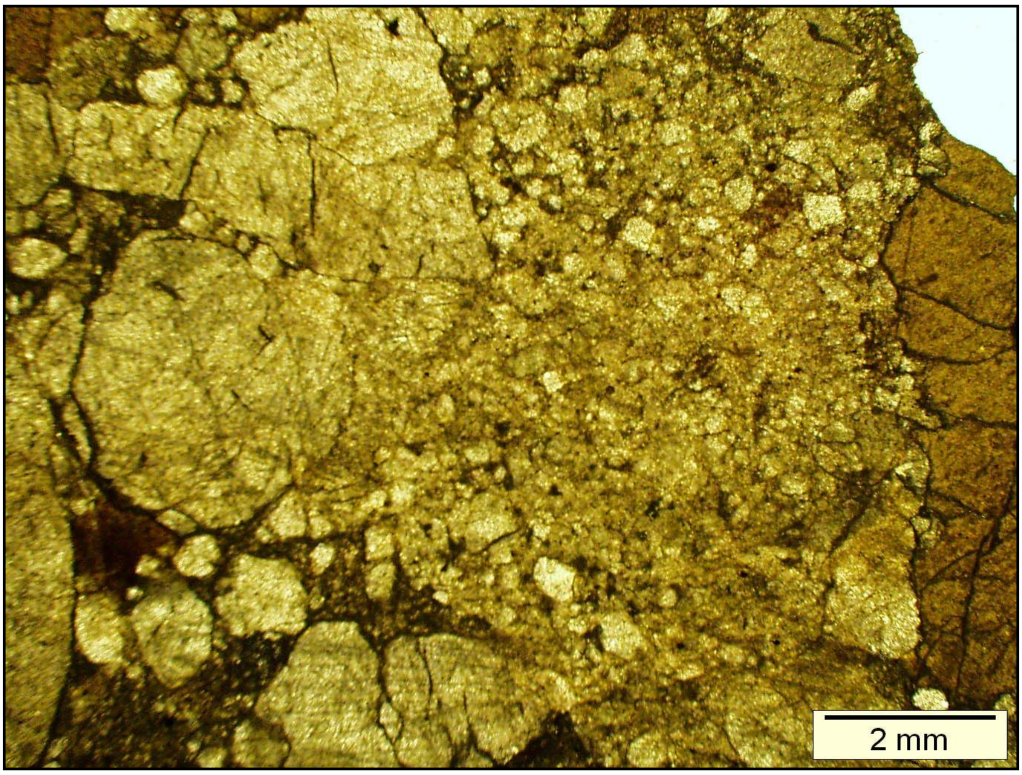

Figure 26: C1 image before grain estimation

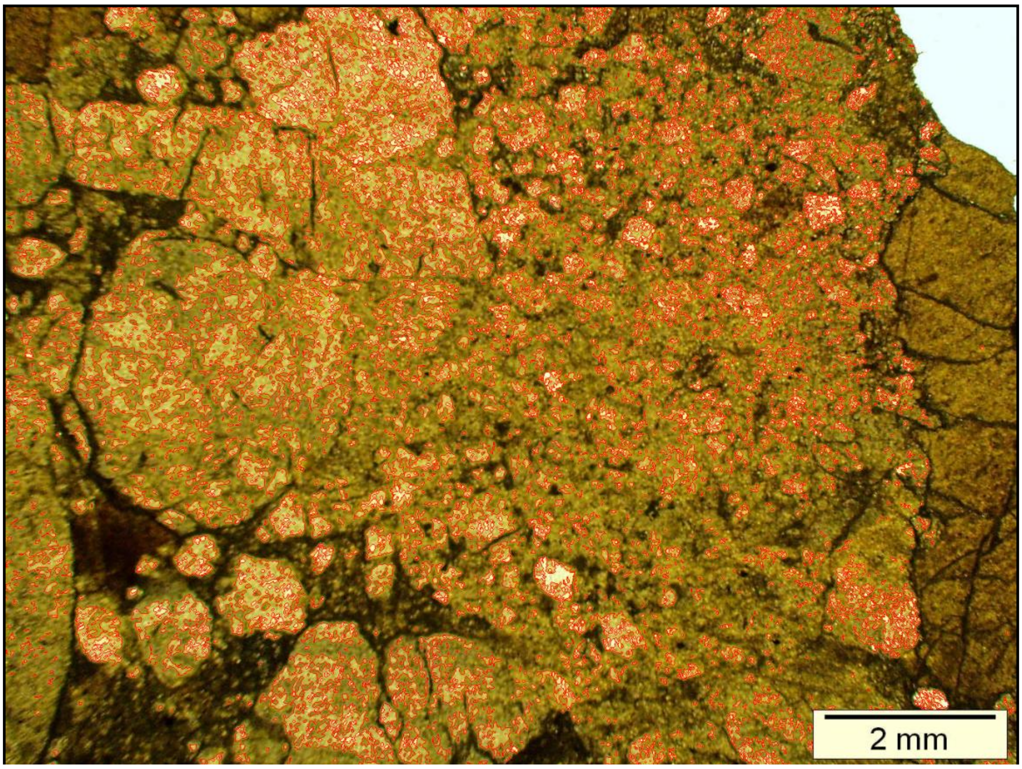

Figure 27: C1 image after grain estimation

2. Fine Sandstone (S1)

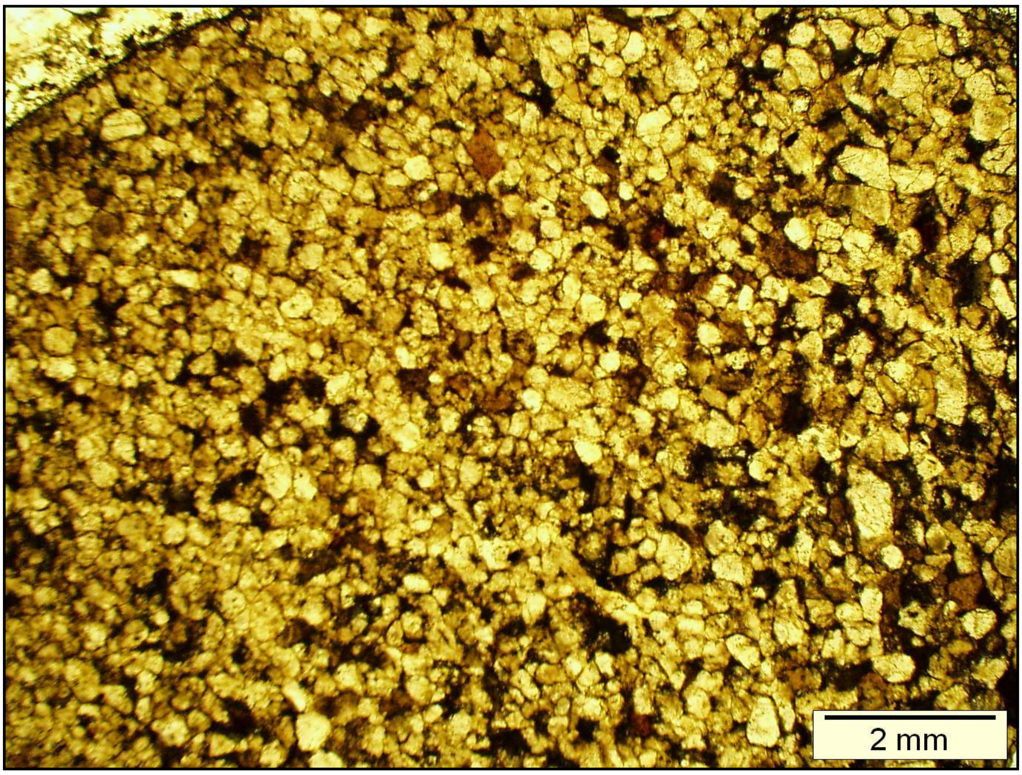

Figure 28: S1 image before grain estimation

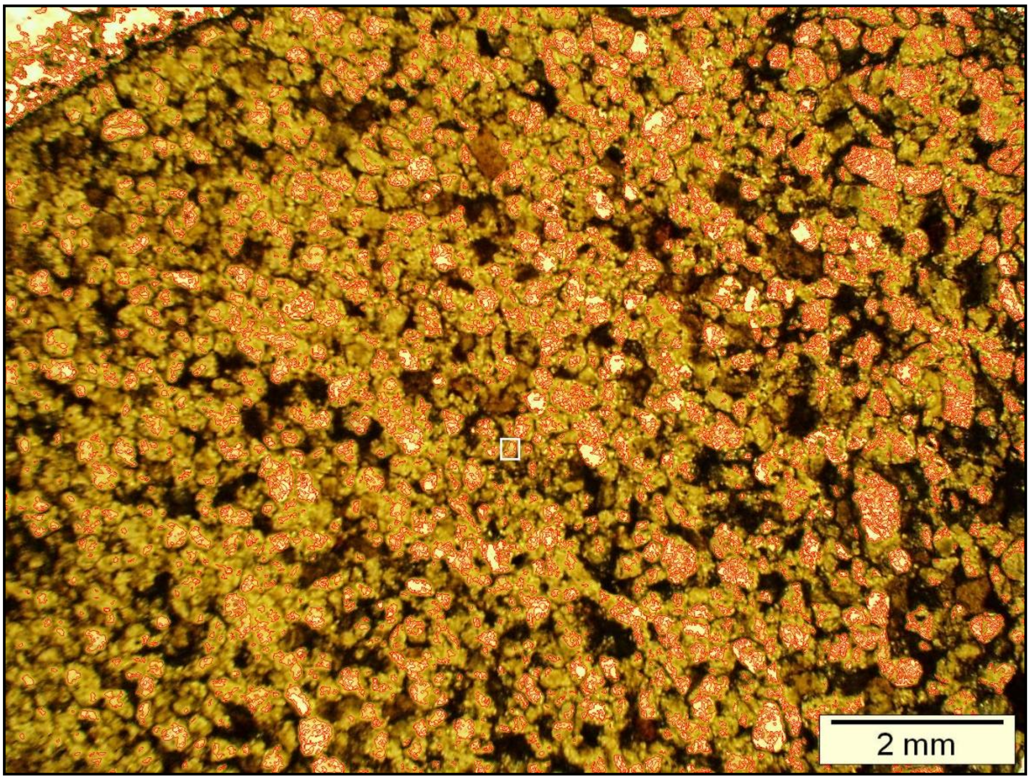

Figure 29: S1 image after grain estimation

3. Conglomerate 2 (C2)

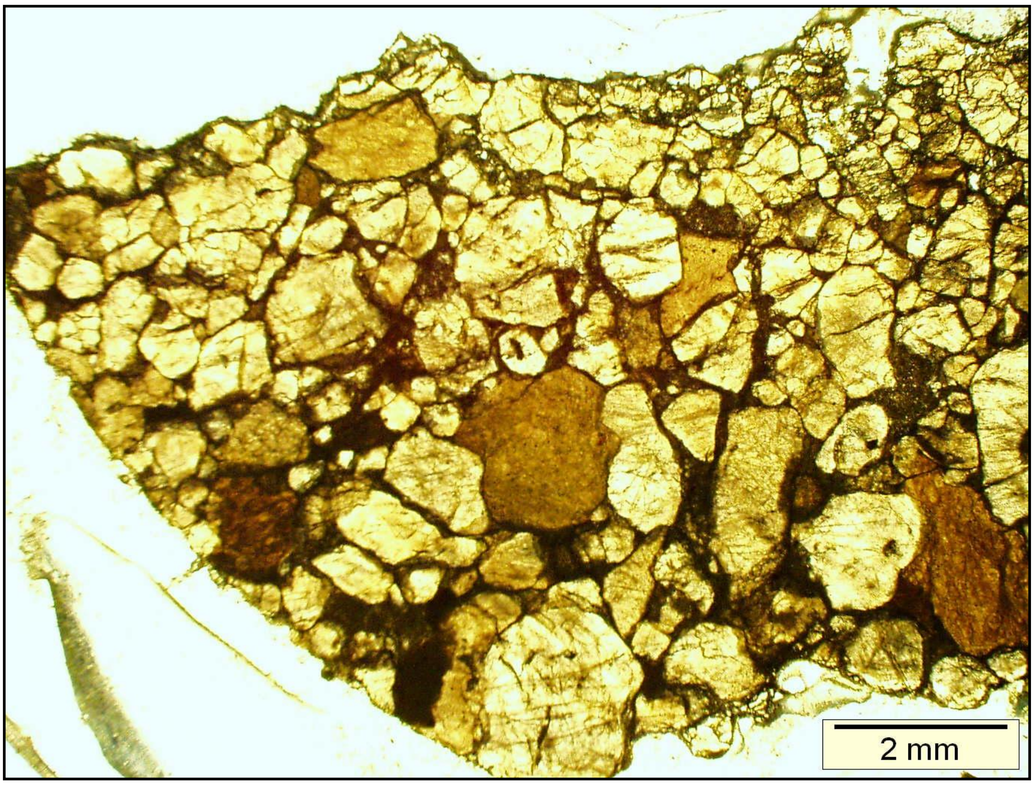

Figure 30: C2 image before grain estimation

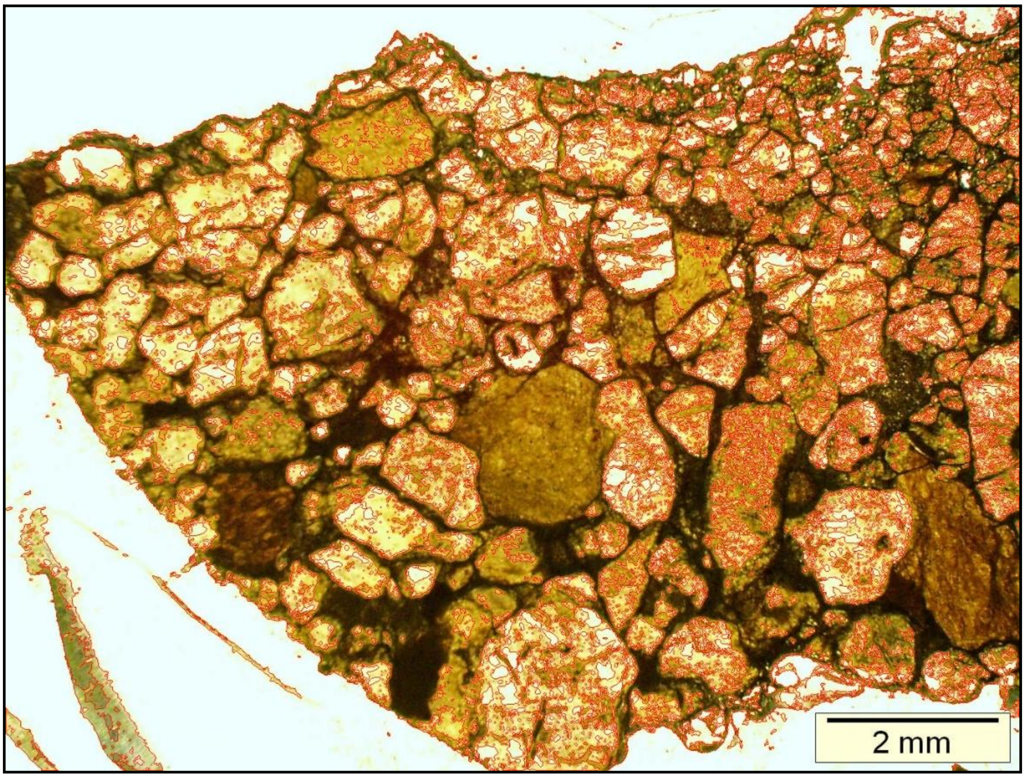

Figure 31: C2 image after grain estimation

4. Coarse Sandstone (S2)

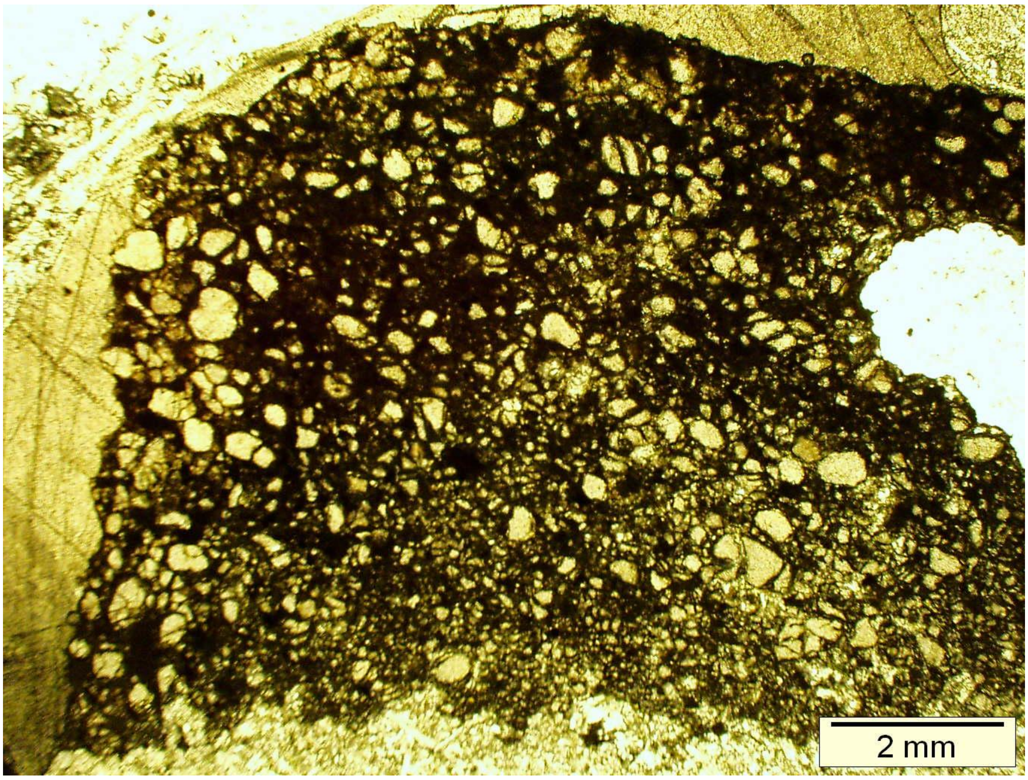

Figure 32: S2 image before grain estimation

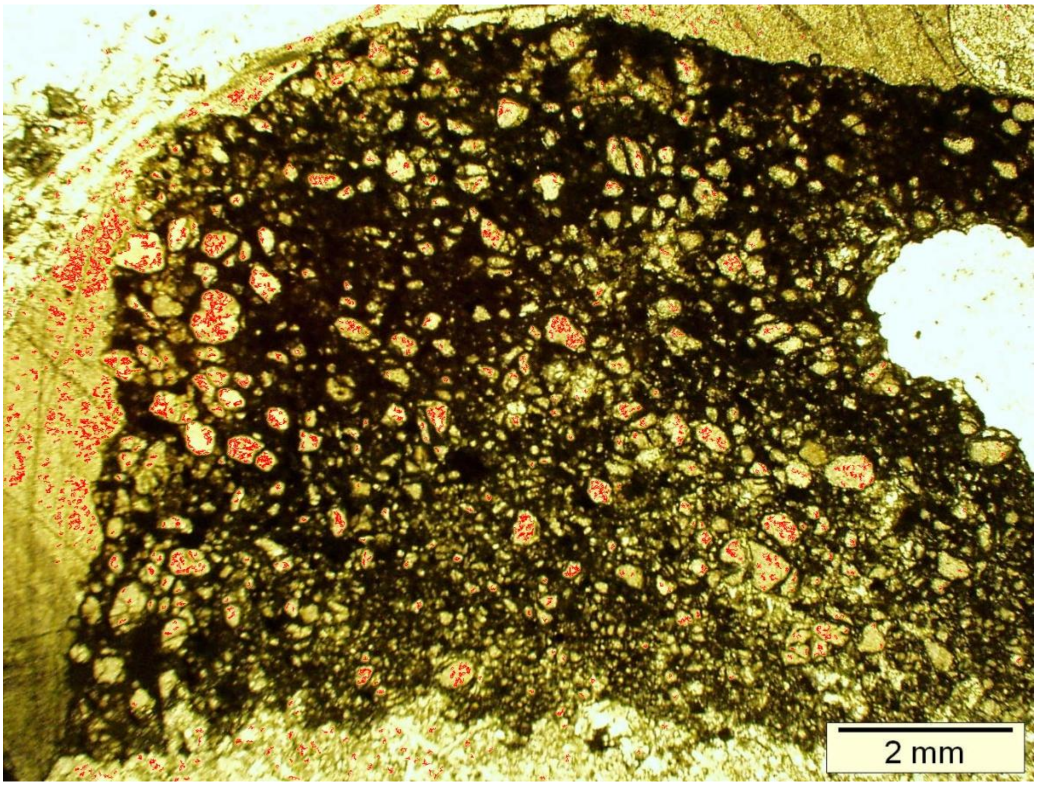

Figure 33: S2 image after grain estimation

In the software, data of the selected grain are available. Variables such areas, length, width, and perimeter are being estimated based on the colour contrast selected. To analyse the grain size distribution, width versus length graph were plotted and the result are as shown:

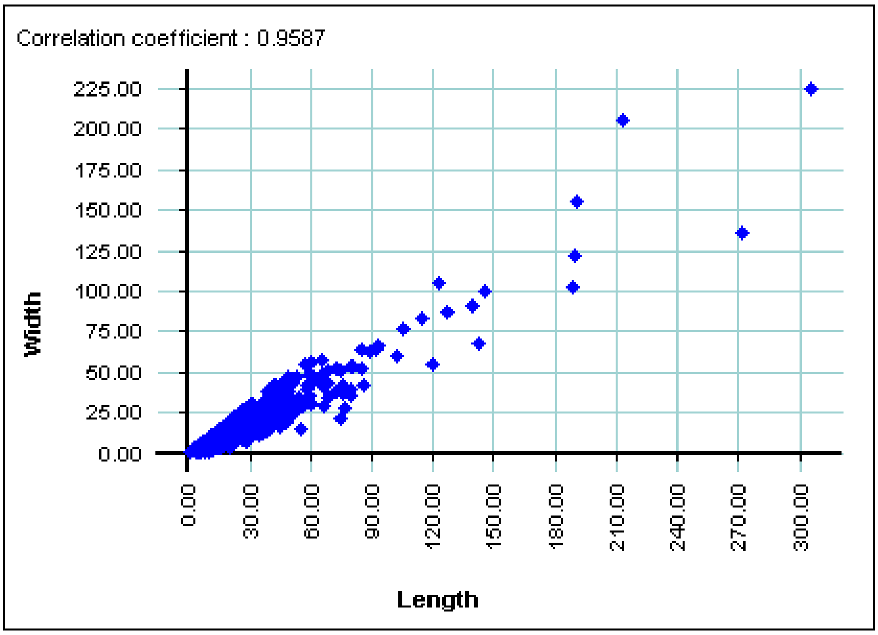

Figure 34: C1 grain size distribution. The size is estimated to be 50 - 60 microns

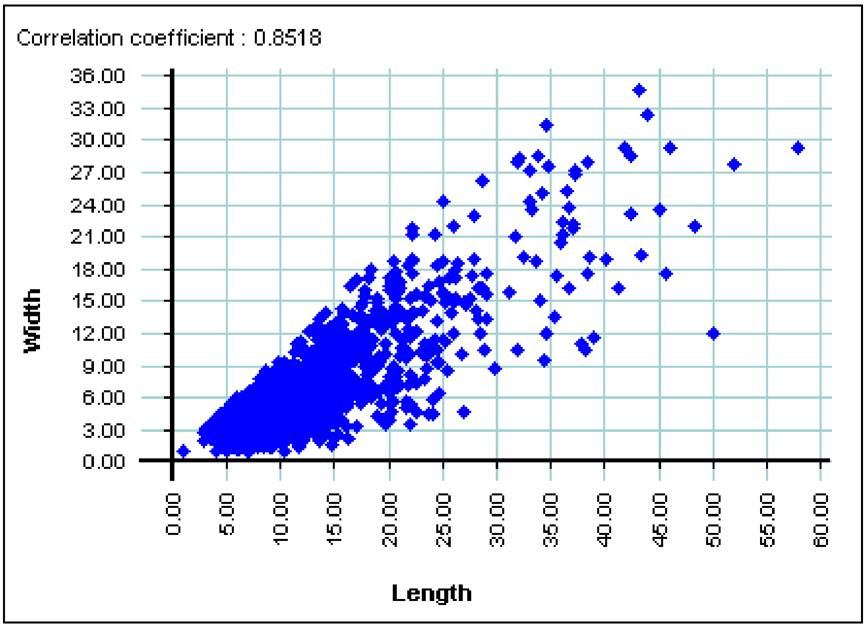

Figure 35: S1 grain size distribution. The size is estimated to be 11 - 17 microns

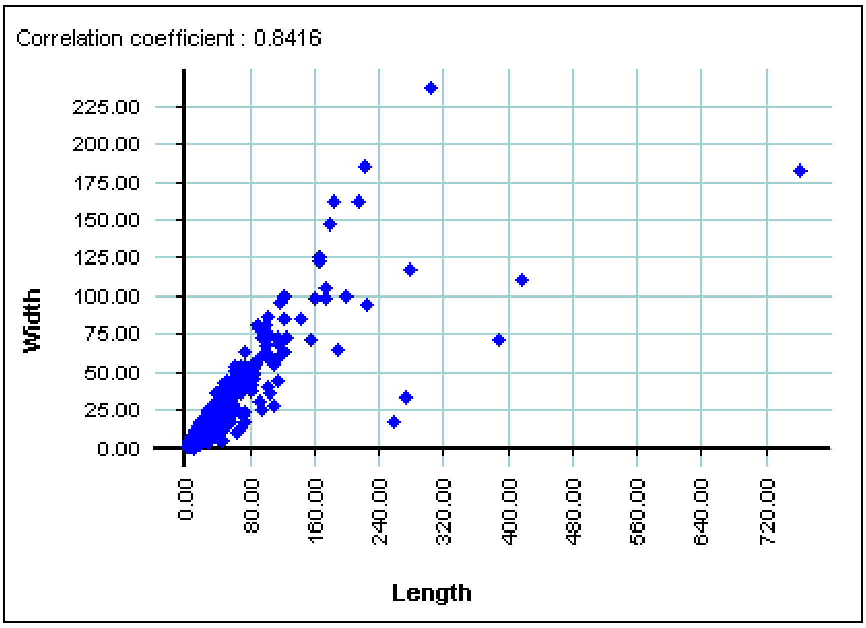

Figure 36: C2 grain size distribution. The size is estimated to be 50 - 80 microns

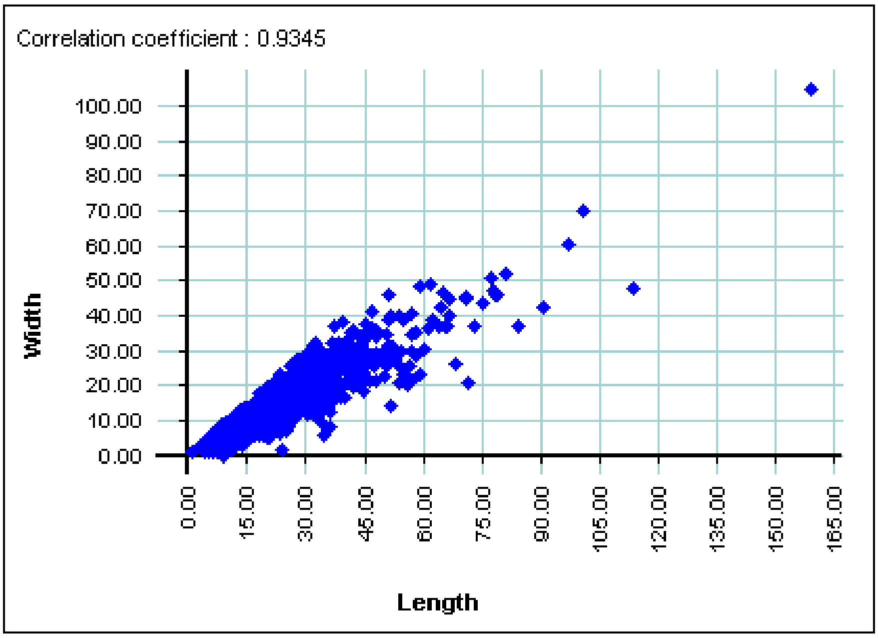

Figure 37: S2 grain size distribution. The size is estimated to be 20 - 35 microns

Based on these results, several analysis and discussion could be made.

Firstly is to analyze the grain size and pore space relationship. From thin section analysis, grain size could be estimated and the result for the pore space were obtained for the Mercury Pressure Porosimetry. By assuming that all other variables are constant such as compaction and sedimentation, the relationship of these two parameters was found.

For sandstone, S1 which consist of fine grain have lower total pore volume compare to the S2 which consist of coarse grain. From this result, it is shown that the relationship between grain size and pore space exist. Same goes to conglomerate where the coarse grain has higher total pore volume compare to fine grain. Hence, from these statements, it shown that increasing size of grain will increase the total pore volume of the rock.

From the analysis made, next step is to analyze whether the grain size and pore space effect the total porosity of the rock. In order to do that, the data of total pore volume and accessible porosity obtained from the experiment were used. However, comparison cannot be made for sandstone and conglomerate. The compaction and sedimentation factors which were neglected in the experiment was the main reason since the process happened naturally to all rock from time to time, which cause the development process of the rock exist today. Different type of rock faces different compaction and sedimentation process in term of time. For example, the rock on the deeper layer faces longer sedimentation process compare to the upper layer. The deeper layer also faced higher and longer compaction process since more layer were made above them will increase the pressure towards the deeper layer. For that reason, to improve the accuracy of the analysis made, sandstone and conglomerate will be compared separately.

The accessible porosity or total porosity result shown that the coarse sandstone has the biggest porosity, followed by fine sandstone, coarse conglomerate, and fine conglomerate. From the data, graph was plotted between total pore volume and accessible porosity and extrapolation of graph was made to predict the effect of these parameters towards porosity. However, due to limited samples and data, estimation of graph needs to made. Based on the porosity versus permeability graph plotted which shown relationship for all the data, the log graph is selected to be the most suitable to be used.

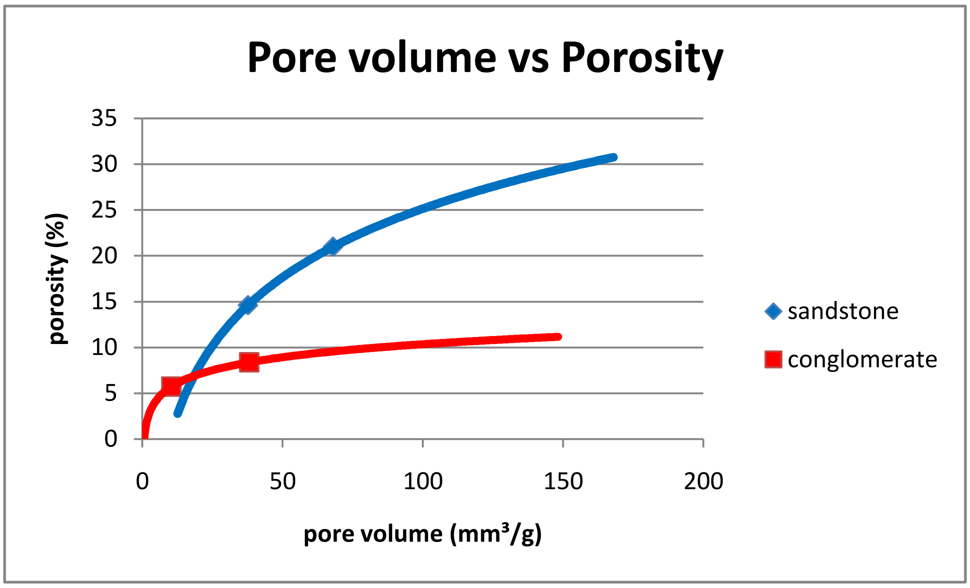

Figure 38: Pore volume versus porosity graph

From the graph plotted, higher pore volume will cause increasing in porosity. The only difference is the increasing rate since other properties which were naturally affecting the porosity such as grain sorting, grain shape, compaction and sedimentation process cannot be avoided. Hence, the graph confirmed that the total porosity is affected by the total pore volume until it reaches maximum porosity where any increasing of total pore volume will not change the total porosity. To prove the hypothesis, porosity versus permeability graph were plotted by considering all the points are related to each other regardless the type of rock.

As mentioned above, the log graph was selected to be used since it gives the most acceptable result. The relationship shown on the graph helps in proving the theory used in predicting the pore volume versus porosity graph. Based on the result obtained, the graph shown that the increasing in porosity plays a factor in increasing of permeability. However, other factors still need to be taken in consideration, in this case shown at the early stage of the graph where increasing in porosity did not change the permeability since the porosity used in this graph is total porosity which cannot precisely be link to permeability compared to effective porosity. Hence, on this experiment, analysis regarding the effect of pore space and grain size towards permeability cannot be done accurately since many other factors need to be taken into consideration.

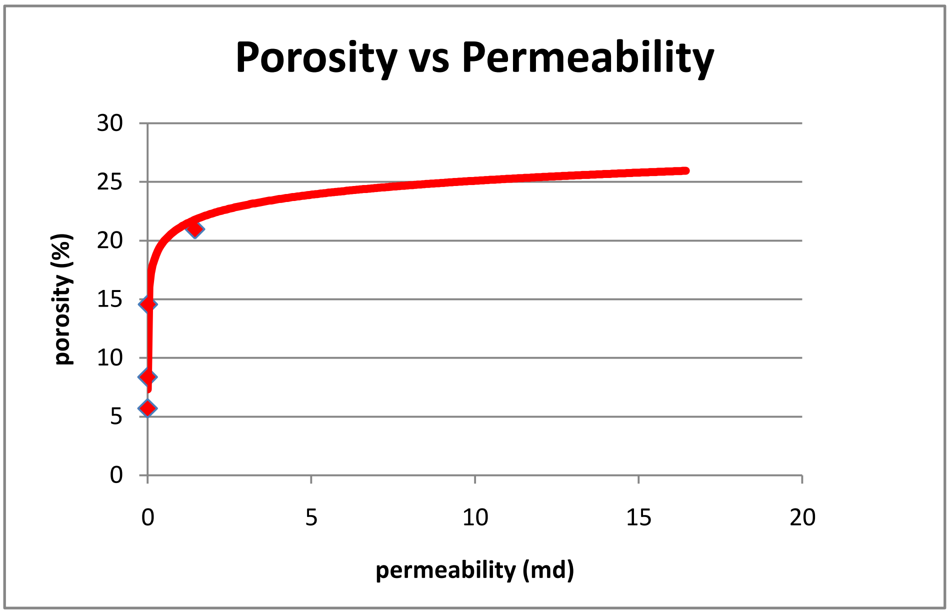

Figure 39: Permeability versus porosity graph

The prediction and analysis were done based on the results obtained from the experiment conducted. The results obtained cannot be said accurately represent the sample since several errors need to be taken into consideration. Since machine was used to run the experiment, the error in result can be expected. However, since the result shown were satisfactory, the result could be assume acceptable. For thin section, the analysis of grain size done based on the picture taken could be affected by human error since the grain size is estimated manually.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The complex pore space geometry of clastic rock is the result of a number of factors, which include grain size, sorting, shape, method of deposition, and compaction following deposition. The results shown that pore space and grain size will affect several properties such as porosity and permeability. It shown that this project appears to be feasible.

The finding at the end of the project was the relationship between pore space and grain size exist. It is proved that the grain size, neglecting other natural properties such as compaction and sedimentation process will affect the total pore space of the rock. Moreover, these two factors are also have an effect towards the total porosity of the rock. Hence, the objective of the project which is to find the relationship between pore space and grain size and whether it has an effect towards total porosity was successfully achieved.

5.2 Recommendation

The porosity and permeability are the main properties that attract interest in the oil and gas industry. These are the main properties that will be compare in order to achieve the objective of this project. However, there are other parameters that can affect these properties such as the sedimentation and compaction. For the future expansion of the study, it is recommended to take into account these two parameters since they can have effects on the grain size, sorting and pore space which will also affect the porosity and permeability.

6.0 REFERENCES

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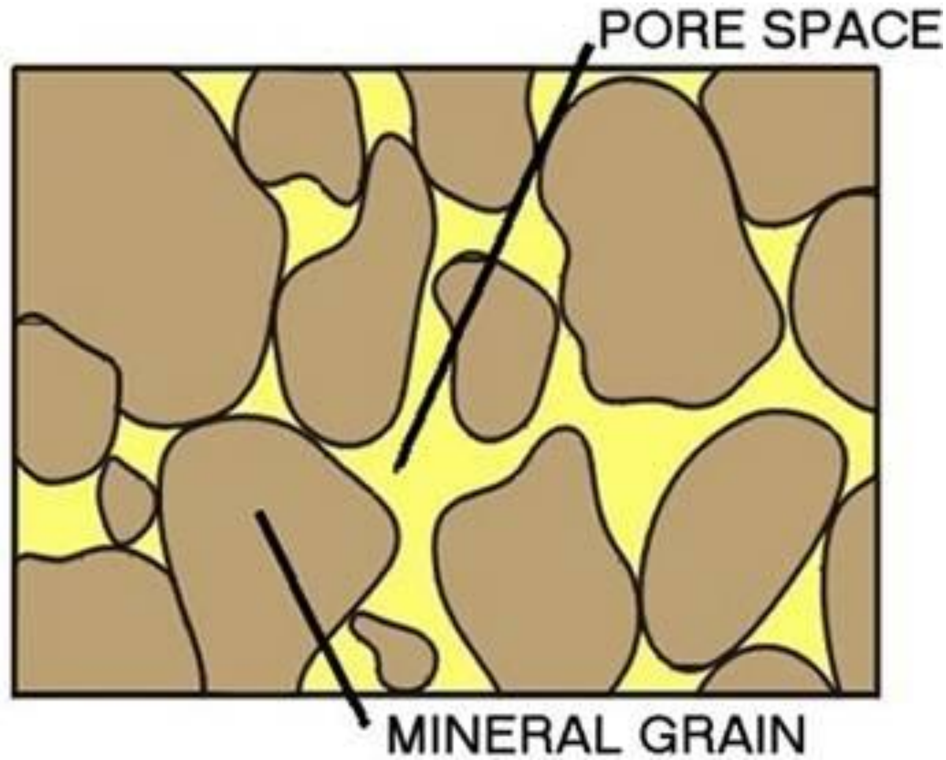
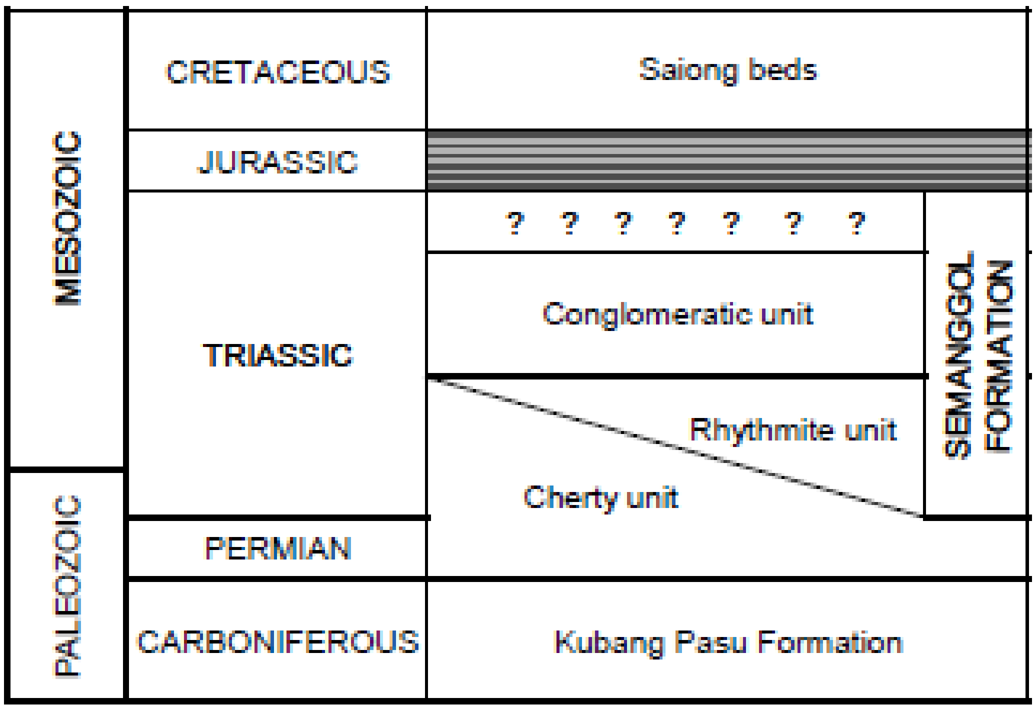
7.0 APPENDICES

Ilustration of Pore Space and Grain Size



The Age of The Semanggol Formation



The Krumbein *phi*(ϕ) scale

φ scale	Size range (metric)	Size range (approx. inches)	Aggregate name (Wentworth Class)	Other names
<−8	> 256 mm	> 10 in	Boulder	
−6 to −8	64–256 mm	2.5–10 in	Cobble	
−5 to −6	32–64 mm	1.2–2.5 in	Very coarse gravel	Pebble
−4 to −5	16–32 mm	0.6–1.2 in	Coarse gravel	Pebble
−3 to −4	8–16 mm	0.3–0.6 in	Medium gravel	Pebble
−2 to −3	4–8 mm	0.15–0.3 in	Fine gravel	Pebble
−1 to −2	2–4 mm	0.08–0.15 in	Very fine gravel	Granule
0 to −1	1–2 mm	0.04–0.08 in	Very coarse sand	
1 to 0	0.5–1 mm	0.02–0.04 in	Coarse sand	
2 to 1	0.25–0.5 mm	0.01–0.02 in	Medium sand	
3 to 2	0.125–0.25 mm	0.005–0.01 in	Fine sand	
4 to 3	0.063–0.125 mm	0.002–0.005 in	Very fine sand	
8 to 4	0.004–0.063 mm	0.00015–0.002 in	Silt	
> 8	0.001–0.004 mm	0.0004–0.00015 in	Clay	
	< 0.001 mm	< 0.0004 in	Colloid	

Note: In some schemes “gravel” is anything larger than sand (>2.0 mm), and includes “granule”, “pebble”, “cobble”, and “boulder” in the above table. In this scheme, “pebble” covers the size range 4 to 64 mm (−2 to −6 φ).