STUDIES OF THE POROSITY DATA ANALYSIS OF SHALLOW WELL ENVIRONMENT SEDIMENTS FOR RESERVOIR QUALITY ESTIMATION IN PULAU BUNTING, YAN KEDAH.

By

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Dissertation submitted in partial fulfillment of

the requirements for the

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Petroleum Geoscience

JANUARY 2014

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

JANUARY 2014

CERTIFICATION OF ORIGINALITY

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

(MOHAMMAD HAIKAL ASYRAF BIN ANUAR)

ABSTRACT

For the first part of this project, the general objective is to evaluate the general geology of the Pulau Bunting. There are several method has to be used to complete and achieve the objective. Fracture analysis method (streonet and rose diagram) has been used to interpret Pulau Bunting metasediment fracture pattern. On the other hand, there are also several elevation data has been taken to help generating the island topography map. Borehole correlation data has also been used to give a basic interpretation of the island lithology.

As for the specific objective of this project, the Porosity data analysis will be use based on the theory of consolidation. The specific objective behind this analysis is to determine the reservoir quality for shallow well environments in Pulau Bunting. This analysis has been derived directly from the ultimate soil settlement in which the soil has been classified based on its initial void ratio, final void ratio and thickness of soil layer. The outcome of the analysis is to produce porosity versus depth profile to observe the porosity distribution in Pulau Bunting. The porosity distribution will then compared with the Menggala Sandstone in Sihapas Formation which has the porosity of 25% at depth between 500m – 1000m at the Central Sumatera Basin. Through the analysis, the initial void porosity gives depth of 118 meter at 25% porosity while the CPI porosity gives depth of 1438 meter at 25% porosity. Therefore, it can be concluded that at depth of 118 – 1438 m the porosity of the area are estimated to be at 25%.

ACKNOWLEDGEMENT

All praises to The Almighty for His bless that I have been able to complete Final Year Project.

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CHAPTER ONE

INTRODUCTION

Reservoir quality can be defined as a measure of quality of reservoir by few parameters (Schlumberger, 2010). There are a lot of factor that could affect the reservoir quality in sedimentary formation. However, most studies have indicated that depositional environment and diagenesis control the reservoir quality. This research is about the analysis of porosity data of shallow well environment sediment for reservoir quality estimation. Porosity can be defined as the proportion of void or pore space in a sediment. There are a lot of factor that can affect porosity:

- Packing Density
- Grain Size
- Sorting
- Post-burial process
  - Compaction
  - Cementation
  - Clay formation
  - Solution
  - Fracturing

All these factor can affect the porosity value which will also affect the reservoir quality estimation. Therefore, by doing porosity analysis, one can safely estimate the reservoir quality for the shallow well environment sediments.

1.1 Background of Study.

Malaysia is a country located near the equator which has a total area of 330,400 km^2. Malaysia can divided into two distinctive part which are the Peninsular Malaysia and East Malaysia.

Pulau Bunting, Yan Kedah was located at the northern part of the Peninsular. The island can be considered as low hills topographically as it highest peak reaching about 140m above sea level. Pulau Bunting is situated 2km away from the Kedah coast in Yan Districy and 12 km away from Gunung Jerai.

According to Ibrahim Abdullah and Che Aziz Ali, Pulau Bunting are made out from two types of rock units which are quartz porphyry and metasediments. Almost 80 percent of the island was occupied by the quartz porphyry whereas the metasediments can only be found at the eastern and northeastern portion of the island.

Void ratio data and borehole log description are obtain from the local entrepreneur project provided by the supervisor. Throughout this whole studies, the lithological description of the Pualu Bunting are made from three borehole data. The borehole data are then used to construct a cross section of the Pulau area to further understand the Shallow well environment in the area. On the other hand, the void ratio data is being analysed by referring to the Consolidation Theory and the porosity profiling concept.

Figure 17: Google earth view of Pulau Bunting

1.2 Problem Statement

This particular study is focused to evaluate the porosity distribution and porosity profile in shallow well environment based on the consolidation theory for reservoir quality estimation. Porosity is one of the characteristic uses to define reservoir quality. Any increment in the porosity value will probably increase the reservoir quality. Most of the study indicates that these two factors plays a major rule in affecting the reservoir quality: Depositional environment and burial diagenesis. Both of this factor has a direct impact on porosity. Failure to recognize the depositional and diagenesis effect on porosity could lead to serious errors in reservoir volume calculation and impact flow rate predictions. Therefore this project is hope to be relevant in order to determine:

- The significance of analysing void ratio data of shallow well environment.
- The relationship between shallow well environment porosity with reservoir quality
- Methods and theories applicable to construct porosity versus depth profile

1.3 Objectives

1.3.1 General Objectives

- To understand local geology in Pulau Bunting
- To produce geological map of Pulau Bunting
- To interpret streonet and rose diagram of bedding plane in Pulau Bunting

1.3.2 Specific Objectives

- To obtain initial void ratio porosity
- To analyse void ratio data.
- To calculate the CPI porosity
- To construct porosity versus depth and CPI porosity versus depth profile of the shallow well environment sediments for reservoir quality estimation based on the consolidation theory.

CHAPTER TWO

LITERATURE REVIEW

2.1 Study Area

As been stated before, Pulau Bunting is located at the northern part of Malay Peninsular and within the Straits of Melaka.

According Madon, M. and Ahmad, M. the strait of Melaka was the least explored sedimentary basinal areas in Malaysia. Straits of Melaka is a shallow seaways which underlain by up to 1600m of Tertiary sediments. The strait is located in between Peninsular Malaysia and Sumatera. There are a lot of study has been conducted to determine the geology of the straits. Geographically, the northern strait of Melaka, offshore Perak and Kedah is a part of North Sumatera basin. On the other hand, the south part of the straits, offshore Selangor and Johor probably belongs to the Central Sumatera basin.

The North and Central Sumatera Basin was form due to crustal extension associated with an oblique convergent margin. (de Coster, 1974). Both basin was characterised by fault bounded grabens. As mentioned above, the northwestern part of the straits which includes Perlis, Kedah and Perak is underlain by up to 1600m of tertiary sediments. According to Hutchinson (1993), the pre-tertiary basement geology of Peninsula Malaysia continues uninterrupted into Sumatra with no major structural offset. A combination of NW-trending horst and grabens and N-S grabens dominated the basement structure.

During Eocene-Oligocene, both basin has undergone rifting process. In later event, probably during Miocene until present, these basin underwent postrift phase during which marine sediments were deposited. According to Katz and Dawson (1996), the nonmarine lacustrine basins that developed in synrift extensional grabens became the sites of organic source rock deposition contributing to most of the oil accumulation in Central Sumatera Basins.

In 1985, PETRONAS has divided the straits of Melaka area into Blocks PM1 and PM15. However, in the year 1996, PETRONAS has re-classified the Melaka straits area into three new blocks which are: PM320, PM321 and PM322. Pulau Bunting was located in the PM321 blocks which also known as central graben area.

The central graben area was located at the central part of the PM321 blocks and at the east of Melaka platform and Asahan Arc. It stratigraphy was believed to be in trend with the Central Sumatera Basin and of the grabens in PM322.

Greenway and Goh (1989) has analysed the geology of this area and concluded that the pre-Tertiary basement consist of metamorphic quartzites, shale and limestone the grabens in the Melaka Straits were formed due to crustal extension during Early Tertiary times. The main reservoir objectives in these graben are the synrift siliclastic sediments of Eocene-Oligocene Permatang Group. In Central Sumatera Basin, Permatang fluvial sandstone has been proven as hydrocarbon reservoir. The interbedded lacustrine shale act as top seal and source rock for the hydrocarbons. Only one well (Port Kelang-1) has been drilled in the Central Graben (PM321) to test the synrift play. Port Kelang-1 found traces of oil show, which indicates that there is working hydrocarbon system in this area

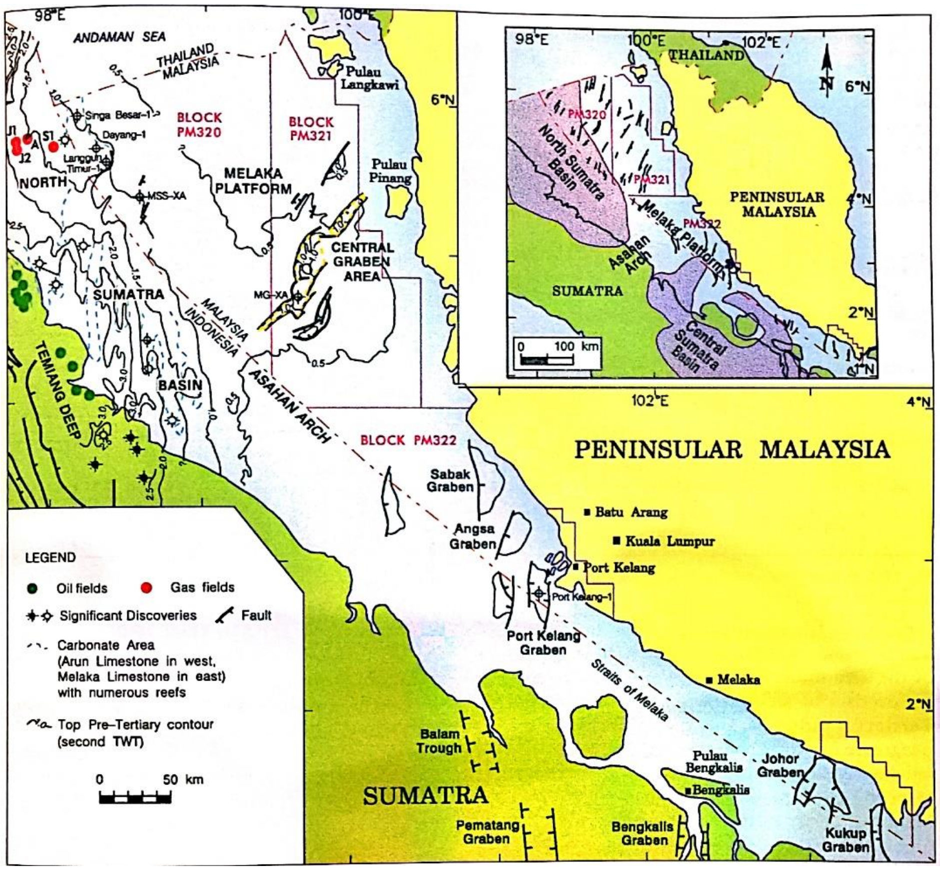

Figure 18: Structural elements of the Straits of Melaka. The Malaysian part of the straits is regarded as continuation of the North and Central Sumatra basins.

Void ratio data and porosity data were acquired based on the clastic sediment samples from Pulau Bunting, Kedah. This area is geologically made out from two types of rock units which are quartz porphyry and metasediments Since the study area which is Pulau Bunting located in adjacent to the central Malacca Straits sedimentary basin, it is possible that the area has petroleum province.

2.2 Consolidation Theory

Karl von Terzagi (1943) states that "consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air". Braja M. Das (1994) on the other hand states that consolidation is a "Process the reduction of bulk soil volume under loading due to flow of pore water". Consolidation may occur due to:

- Deformation of soil particles
- Relocation of soil particles
- Expulsion of water or air from the void spaces

When load is apply to the ground surface, the volumetric of the underlying soil will decrease due to the compressional forces. Patrick J. Fox (n.a) states that, consolidation is actually a process which occur when there is reduction in volume due to the expulsion of water from the pores of the soil. The effective stress and the volumetric of the soil will also increase with the expulsion of the excess pore water pressure. The consolidation of the soil can be determine by assuming that the compression forces is one dimensional occurring only in vertical direction. This assumption can only be made when:

- The width of the loaded area exceeds four times the thickness of the clay stratum
- The depth of the top of the clay stratum exceed twice the width of the loaded area
- The compressible material lies between two stiffer soil strata whose presence tends to reduce the magnitude of horizontal strains (Leonard, 1976).

In general, the soil settlement causes by load may be divided into three broad categories which are: Immediate Settlement, Primary Consolidation Settlement and Secondary Consolidation Settlement.

1. Immediate settlement is caused by the elastic deformation of soil without any alteration to its moisture content. The immediate settlement calculation can be made based on equation derived from the theory of elasticity.
2. Primary consolidation settlement is caused by the volume reduction of saturated cohesive soil due the expulsion of water that occupies the void spaces

3. Secondary consolidation settlement is observed in saturated cohesive soil and causes by the plastic adjustment or alteration of the soil fabrics. It follows the primary consolidation settlement under a constant effective stress.

The magnitude and the rate of both primary and secondary consolidation settlement can be determine by the **One Dimensional Laboratory Consolidation Test.** This test was first suggested by Terzaghi (1925) in which it is performed in a consolidometer (Figure 3). During this test, a soil sample is usually placed inside a metal ring couple by two porous stone at the top and bottom. Load is then applied to the soil sample through a lever arm and the compression magnitude is determine or measured by the micrometer dial gauge. The soil specimen is kept under water during the test. Each load will be applied for 24 hours. After the time period, the load is usually doubled and the measurement of the compression continued. The dry weight of the soil sample is recorded at the end of the whole test.

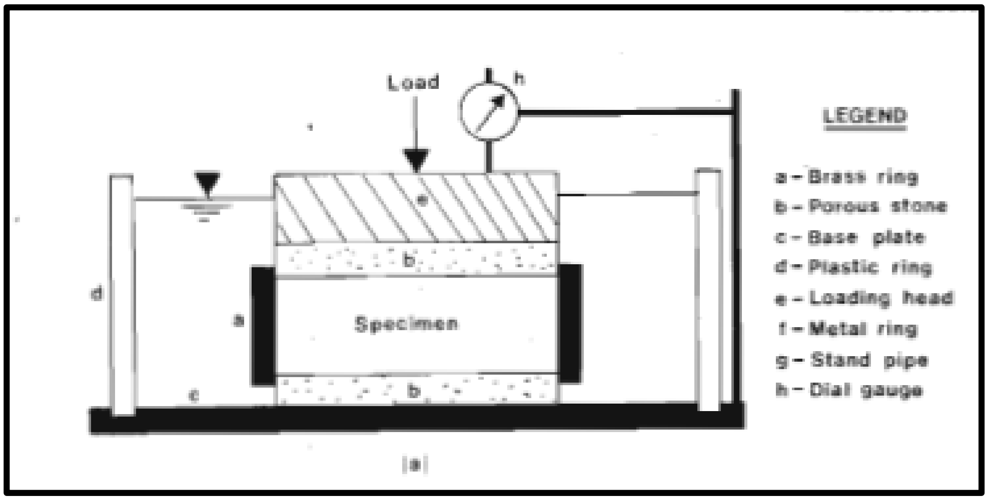

Figure 19: Consolidometer

2.3 Atterberg Limits

The soil strength and settlement characteristic can be obtain through the atterberg limit test. This test main purpose is to measure the moisture content of a fine grained soil such as its shrinkage limit, plastic limit and also liquid limit. The characteristic of the soil can be altered due to its moisture content. The soil characteristic can be divided into 4 states which are: solid, semi-solid, plastic and liquid. The soil behaviour and consistency are different in each of the state. Solid Soil become crumbly semisolid soil when the moisture content of the soil reached the shrinkage limit. As the moisture content of the soil increase, the soil begin to swell in volume. Further swelling could be cause due the increase in the moisture content. At this point, if the moisture content of the soil exceed the soil plastic limit, it will transform into a malleable plastic mass. On the other hand, the soil will then transform into a viscous fluid if and only if the soil moisture content exceed its liquid limits.

Written below are further explanation regarding the Liquid Limit (LL), Plastic Limit (PL) and Shrinkage Limit (SL).

- Plastic Limit (PL) can be define as moisture content at which soils begins to behave as plastic material
- Liquid Limit (LL) defined as the moisture content at which soil begins to behave as a liquid material and start to flow.
- Shrinkage Limit (SL) can be defines as moisture content at which no further volume change occurs with reduction in moisture content.

CHAPTER THREE

METHODOLOGY

3.1 General Geology

- Surface Map
- Cross Section Diagram
- Streonet
- Rose Diagram analysis

The purpose of this project is to study the porosity data analysis of shallow well environment sediments based on borehole log data. Therefore, the main methodology used in this project are mostly analysis of the borehole logs data and report.

However, since the basic map and geological map of this project is a requirement, the first step is to construct a contour map of the Pulau Area. The contour map was constructed by using a GPS data to record the coordinates and the ground elevation. These data are then combined together with another 250 elevation data extracted for Google Earth software. All the data would then be converted into a surface map by using the Surfer software. Through the software, each contour line of different elevation has been assigned a different colour.

The next step in this project is to draw or construct a cross section diagram for the Pulau area based on three different borehole data. The lithology of the cross section is coloured for better visual representation.

Streonet and Rose Diagram on the other hand are made based on fault data collected during site visit at Pulau Bunting. The streonet and Rose Diagram are both construted by using the Stereonet 9 software.

3.2 Data Collection and Compilation

- Porosity data

The porosity data used in this project can be calculated from the void ratio data obtain from the One Dimensional Consolidation Test results. The test does provide both initial and final void ratio data which can be used to calculate the initial void ratio porosity, ultimate settlement of the soil, Constant Plastic Index (CPI), Void Ratio Function (VRF) and CPI porosity.

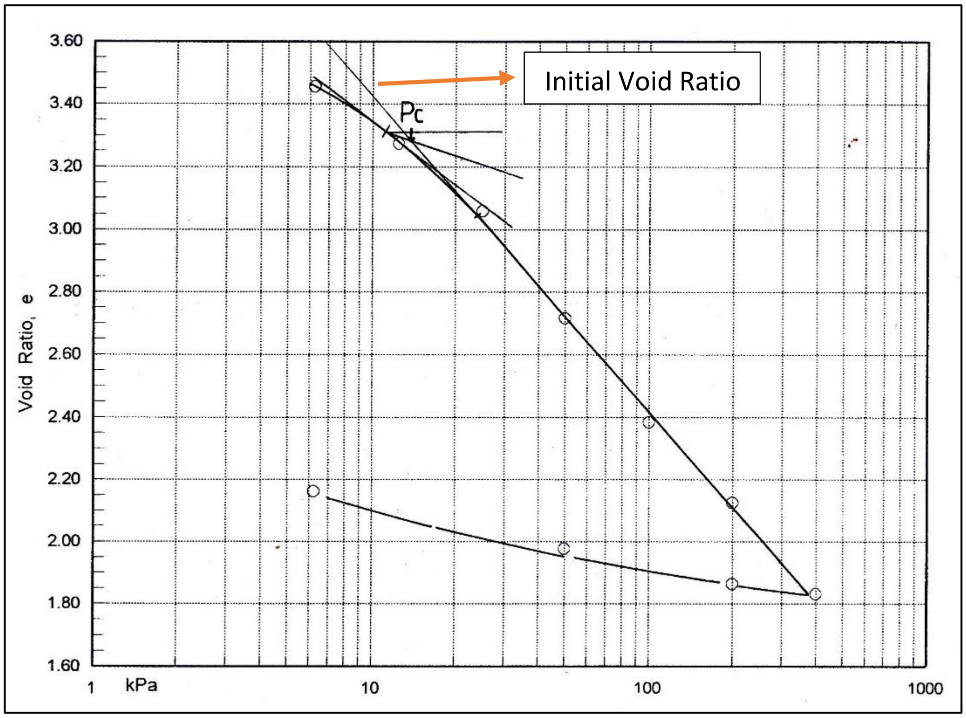

Figure 20: Void ratio versus Pressure graph. The initial void ratio and final void ratio value can be obtain from this graph

The initial void ratio porosity can be calculated by using the equation below:

$$\emptyset = \frac{e_0}{1 + e_0}$$

Where,

Ø = Porosity e_0 = Initial Void Ratio

3.3 Data Analysis

- Consolidation Theory
- Porosity Profiling Concept

Based on the consolidation theory, the ultimate settlement, S_{ul} is resulted from the changes in the void ratio value over the depth of the consolidating layer. This equation is use mainly to calculate the ultimate settlement of a single compressible layer:

$$S_{ul} = \frac{(e_f - e_0)H_0}{1 + e_0}$$

Where,
S_{ul} = Ultimate Settlement
e_f = Final Void Ratio
e_0 = Initial Void Ratio
H_0 = Thickness of the layer (m)

Halim (2013) stated that, the Constant Plastic Index (CPI) Method can be developed by using the ultimate settlement of the soil, $S_{ul.}$ CPI method is actually an "approach model based on the theory of consolidation". Halim's CPI method can be used to describe the expansion of consolidation based on the variation of the ultimate settlement, $S_{ul.}$ Consolidation is a complex process as the change of surface and base of stratum occur as the consolidation builds up which will then develop pervious and impervious base of the layers (Muiz, 2013). One-dimensional theory on consolidation describe that the consolidation happen due to the weight of the soil itself without external forces. Even in this theory, consolidation is still complex due to the variation in the vertical load acting up on the soil and the change in drainage length as the deposit builds up and compressed.

The CPI porosity was calculated by integrating to void ratio function (VRF) using the modified Constant Plastic Index, CPI method as shown in the equation below:

$$CPI = \frac{\ln(\frac{\Delta eH}{S_{ul}})}{lne_0}$$

Where,

CPI = Constant Plastic Index H = Thickness (m)

Δe = Changes in Void Ratio

E_0 = Initial Void Ratio

S_{ul} = Ultimate Settlement

$$F(e) = {e_0}^{cpi}$$

Void Ratio Function Calculation (VRF) where,

F(e) = Void Ratio Function

e_0 = Initial Void Ratio

CPI = Constant Plastic Index

$$\emptyset CPI = \frac{F(e)}{1 + F(e)}$$

CPI porosity calculation where,

ØCPI = CPI porosity

F (e) = Void Ratio Function

The porosity profiling concept is made based on the porosity and CPI porosity obtain from the void data. Porosity distribution graph can later be constructed by using the porosity and CPI porosity value with depth to determine the porosity value at the predicted or interpreted reservoir interval.

CHAPTER FOUR

RESULTS AND DISCUSSION

Final Results:

Figure 21: Outcrop 1, Pulau Bunting

Figure 22: Outcrop 2, Pulau Bunting

Figure 23: Granite outcrop in Pulau Bunting

Figure 24: Contact between metasediment and granite

4.1 Lithological Description

Pulau Bunting’s lithology is generally comprises of 2 types of rocks which are: Granite and Metasediment. Throughout the observation made at the island, 80 percent of the island was made from granite whereas the remaining 20 percent is the metasediment. The metasediment could only be found at the NE direction of the island. The contact are for both rock can be seen in Figure 6. The contact area is located at the northeast side of the island.

By definition, metasediment is a type of sedimentary rock that appears to have been altered by metamorphism process. In order to determine the original sedimentary rock, the overall composition of the rock can be used. As for now, there are no thin section yet to further confirm the original rock for the metasediment rock in Bunting’s island. There are 2 major metasediment outcrops all together in bunting island shown in figure 5 and 6. Both of this outcrop has different dipping and fracture system. A lot of strike and dip reading has been take at both of this outcrop. A fracture analysis consist of stereo net and rose diagram to further discuss about the fracture system of this rock.

Granite on the other hand is a type of igneous rock which has granular and phaneritic texture. Most of this rock composition are quartz, mica and feldspar. Granite in this island (figure 5) has a common porphyritic texture and greyish to white in colour. Porphyric texture is a type of texture in which the phenocrysts are larger than the ground mass. There are no thin section analysis data at the moment to further evaluate the granite composition.

4.2 Fracture System

Stereo net can be used to find the intersection between two planes (e.g. the fold axis if folding is cylindrical), to find the angle between two lines, two planes or a line and a plane, to find the restored orientation of a geologic feature such as a cross bed once it is rotated about some axis and to find bisect the angle between two planes (e.g. if you are trying to model kinematic axes or principal stresses associated with conjugate faults). Rose diagram on the other hand

For this particular project, the stereo net has been made based on data collected on Pulau Bunting's outcrop. There are three outcrop all together that can be found on the islands. Strike and Dip data for the bedding plane of each outcrop has been take and use to make the stereo net and rose diagram.

Listed below are the interpretation of the stereo net and rose diagram shown in figure 9 and figure 10:

- Compression force from 165° and 345° direction (NW & SE)
- Major fracture will occur 30° from sigma 1which is at 135° and 315°
- Extension force from 255° and 75° direction (NE & SW)

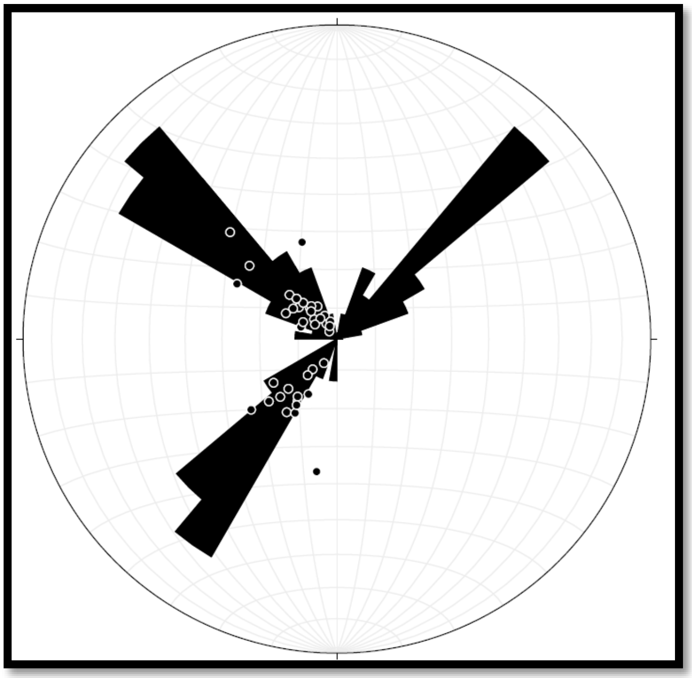

Figure 25: Rose Diagram for Pulau Bunting

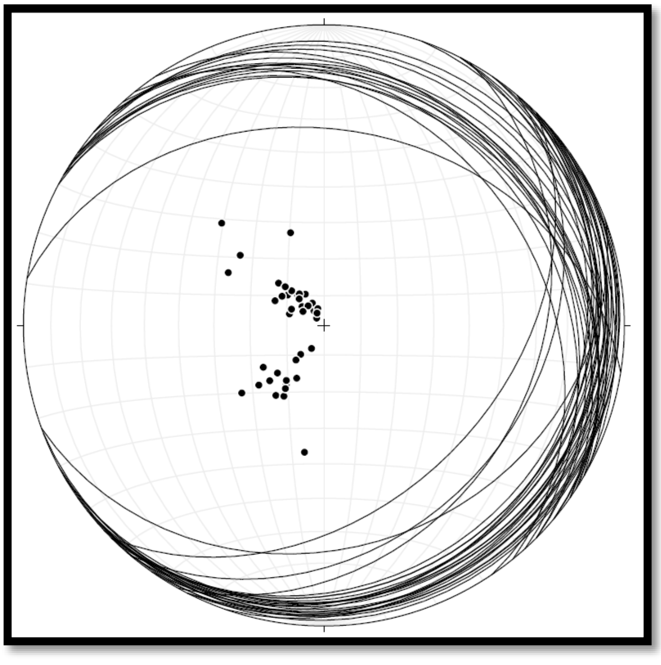

Figure 26: Stereo net for Pulau Bunting

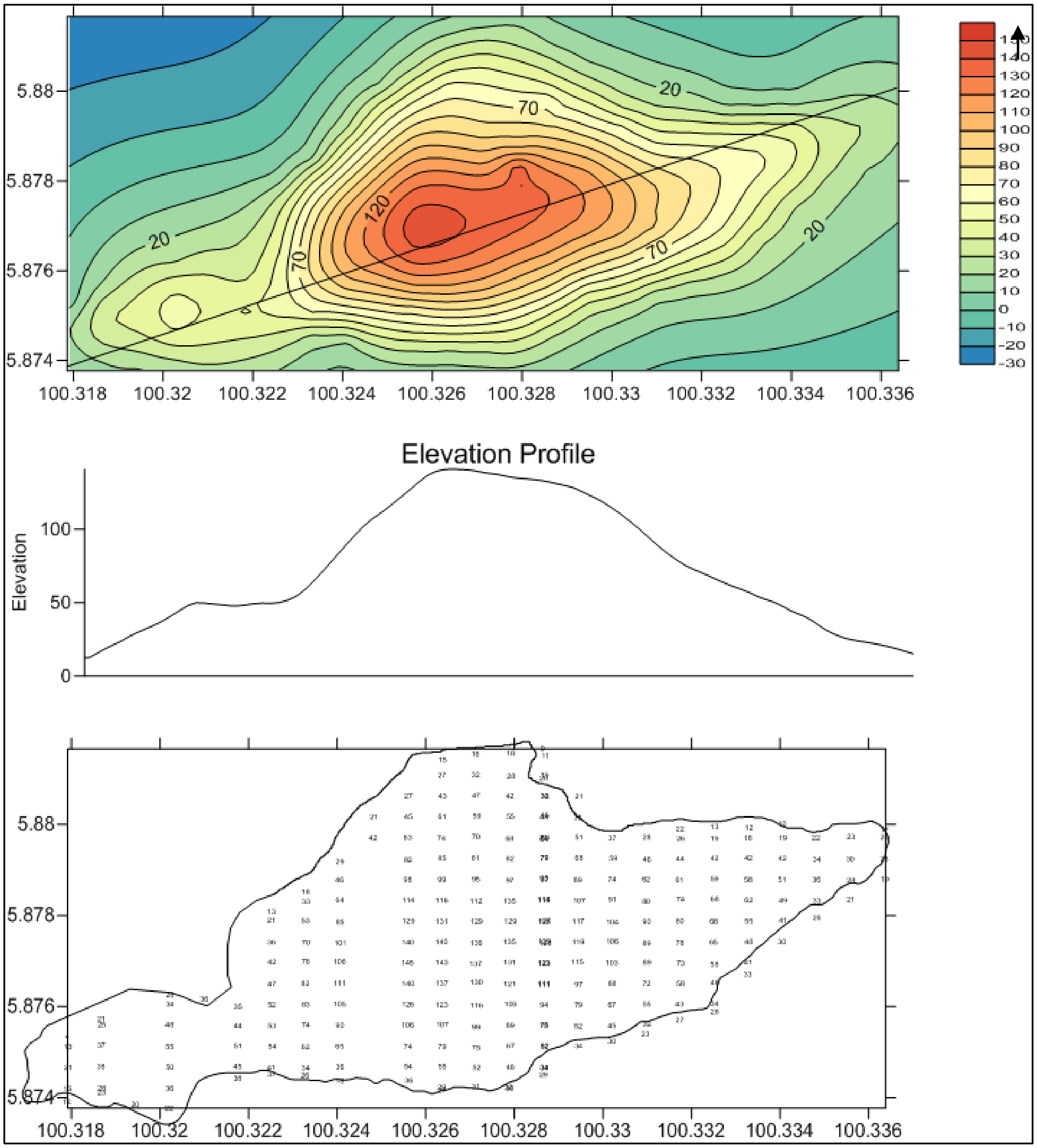

Figure 27: Contour Map, Elevation Profile and Post Map

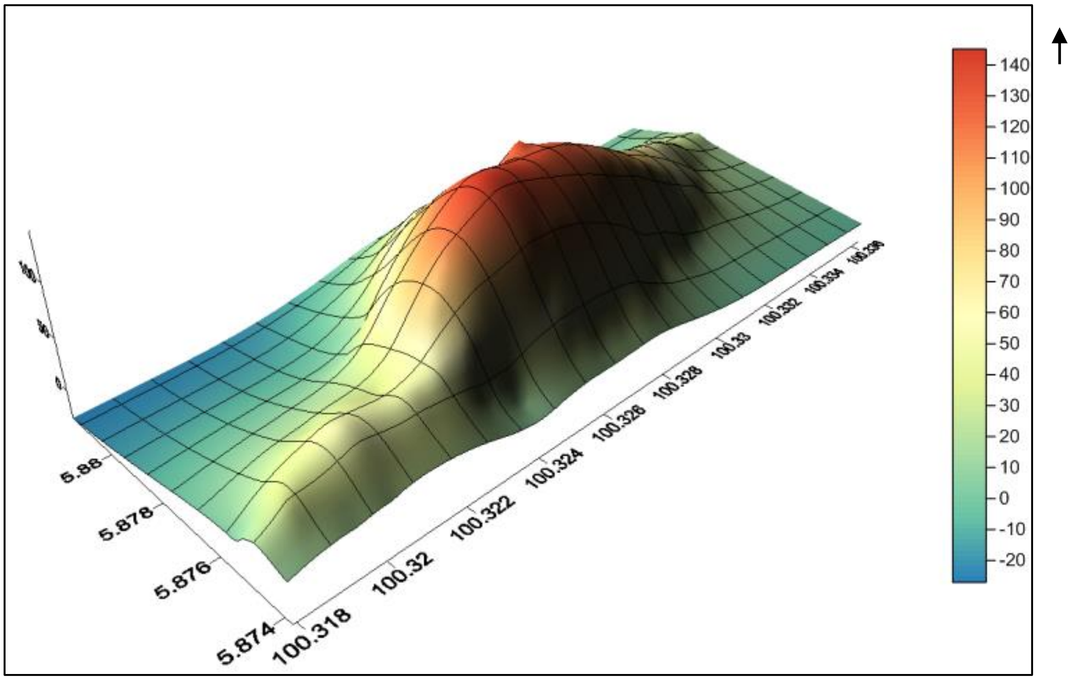

Figure 28: 3D profile of the island

Figure 29: Borehole Location

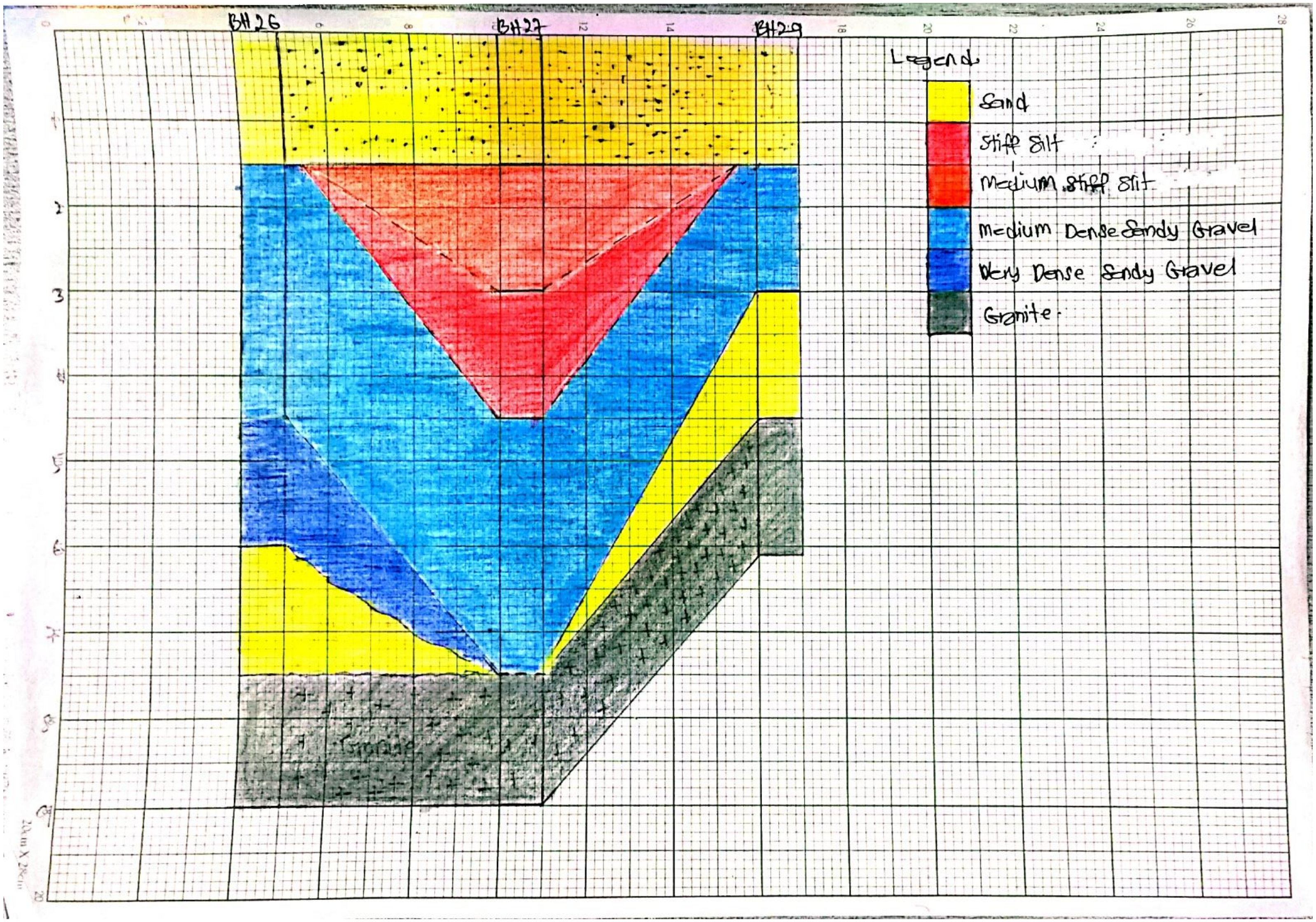

Figure 30: Borehole Correlation

4.3 Structural Geology

A contour map has been made for this particular site based on actual and google earth data. Almost 250 data has been used to generate and create the contour map for the whole island.

Based on the figure 11, the highest peak for the island is approximately 140 meters above sea level. The island increase in elevation almost at the center region. Towards the SW direction the slope is much steeper in comparison with the slope at the NE direction.

The borehole correlation on the other hand has been made based on existing borehole logs. There are 5 borehole logs altogether existed on the islands. 3 borehole logs has been used to construct this particular borehole correlation.

Based on the borehole correlation (Figure 14), about 3 meters beneath the island is mostly top soil. This particular lithology has been used as reference datum. Beneath the top soil, there are some evidence of silt and also sandy gravel. The silt and sandy gravel are both increase in stiffness and dense as the depth increase. Granite is found at the bottom of the borehole correlation. Based on the structure observed from the borehole correlation, the granite is believed to form by uplifting.

4.4 Average Initial Void Ratio Porosity and CPI porosity.

The value for the initial void ratio porosity and the CPI porosity are obtain by using the equation stated in the methodology above. There are 20 values of both initial porosity and CPI porosity for this particular area. The results of the calculation are tabulated in the appendix 2 and 3. All the value for the initial void ratio porosity and the CPI porosity has been sorted according to their depth scale. Once sorted, the average value for each depth scale is calculated to be used for constructing the porosity profile of this area. The result are as in the table 1:

Table 2: Average Initial Void Ratio Porosity value and Average CPI porosity value with depth

Depth of Sample (m)	Average Porosity	Average CPI Porosity
3-6	0.74	0.80
7-12	0.69	0.77
13-18	0.63	0.69
19-24	0.51	0.68

From the table above, it is observed that the value of both porosity decrease with increase depth. This is true, since compaction are one of the reason that cause the porosity to decrease. As the depth increase, the compaction magnitude increase thus forcing the soil volume to be reduced. When the volume of the soil is reduced, the porosity value of the soil decreasing.

Porosity versus Depth Profile

Based on the data tabulated above, below is the porosity profile over depth.

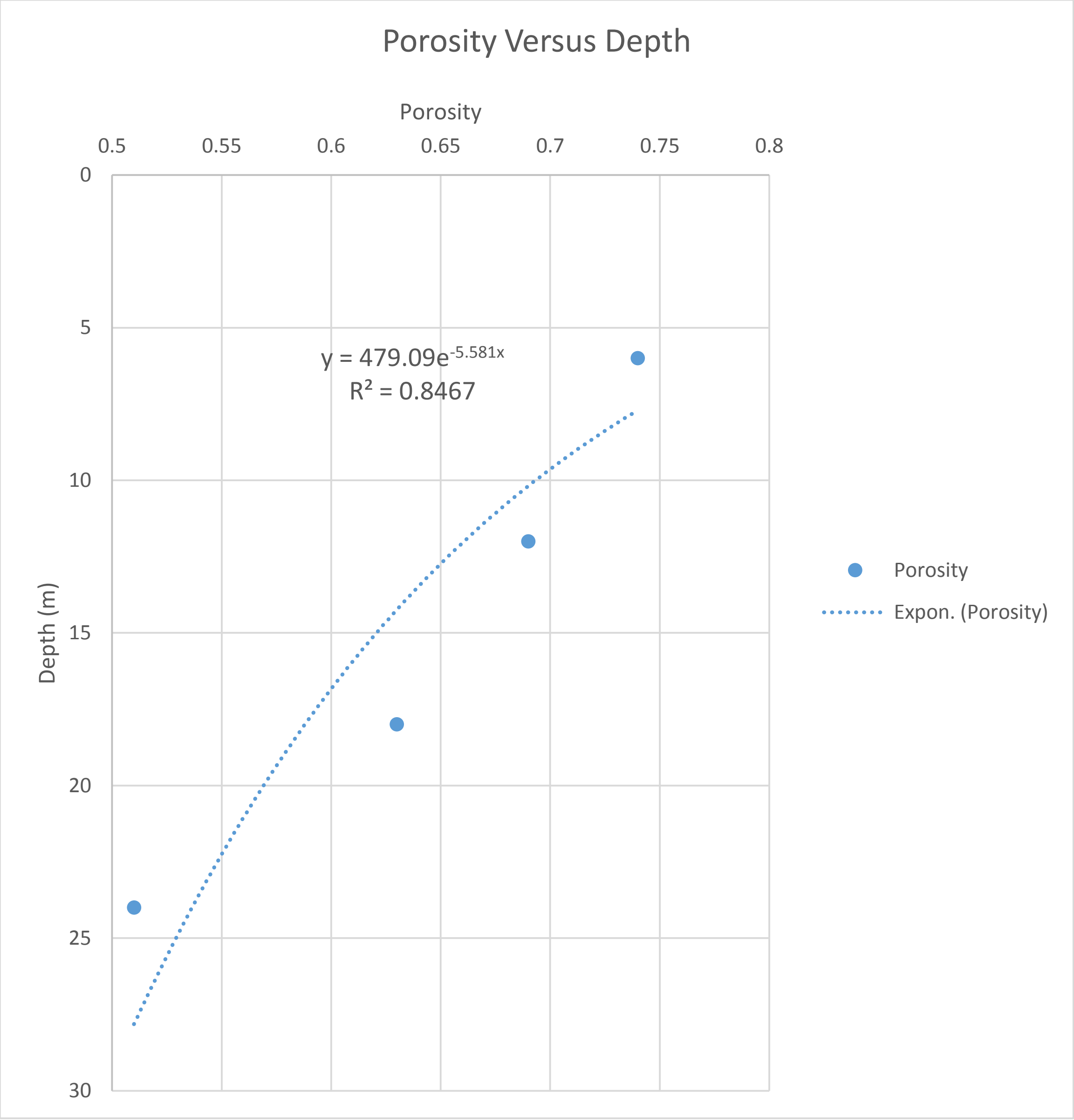

Figure 31: Porosity versus Depth Profile

CPI Porosity versus Depth Profile

Based on the data tabulated above, below is the CPI porosity profile over depth.

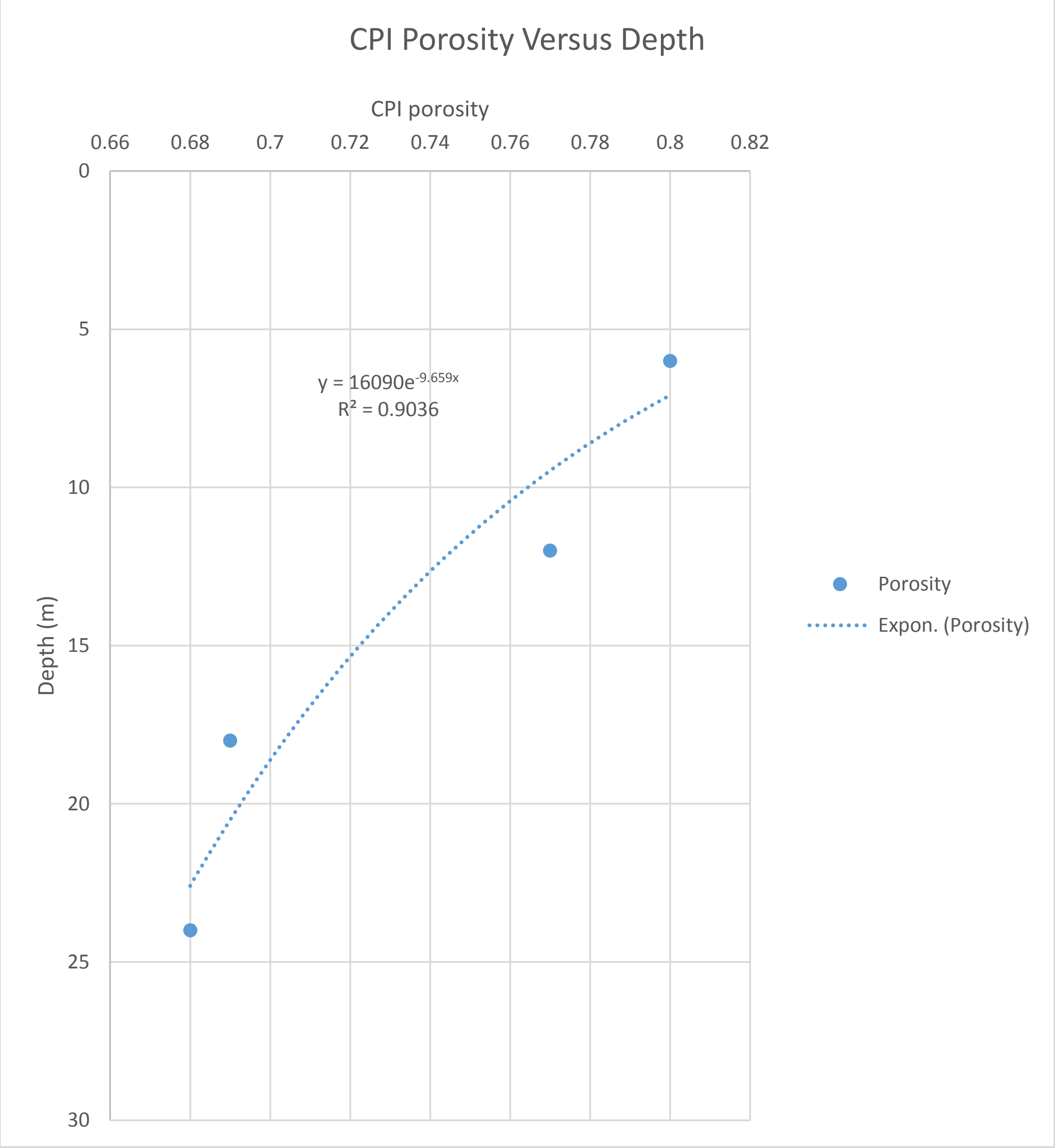

Figure 32: CPI porosity versus Depth Profile

4.5 Porosity Profile Analysis

From the average data of both porosity and CPI porosity obtained above, both porosity result shows decreasing value with respect to the increase in depth. This phenomenon is best explain by the theory of consolidation. Consolidation increase with increase in depth due to compaction. Compaction causes the volume of the soil reduced which indicates that the porosity value are also reduced. Thus, it can be said that, porosity value decrease with depth.

Porosity value is obtain from the void ratio data can only be used for a soil layer that is assumed to homogenous in nature. On the other hand, the CPI value obtain from this analysis can be used to discuss the relationship between the porosity and the variation of consolidation in a layer of soil. According to Halim (2013), CPI porosity can be considered as non-linear porosity integrated to the variation of the shallow well environment soil.

In order to determine the reservoir quality of the shallow well environment, both the porosity profile can be extrapolated up to deeper level. By following the trend line produce in each profile (refer figure 15 and 16), the porosity for expected depth can be safely estimated. The estimation made by using the extrapolation of the porosity profile are particularly true and reliable since, the value of porosity decrease with respect to depth.

Ahmad and Madon (1999) stated that the "porosity of Menggala Sandstone in Sihapas Formation is 25%. Sihapas formation is found at depth of 500m up to 1000m at the Central Sumatera Basin in the Malacca Straits. Pulau Bunting are located in the area which is adjacent to the Malacca Straits thus, extrapolation for both initial void porosity and CPI porosity can be made to matched with the Menggala Sandstone porosity value.

According to the trend line in Figure 15 and Figure 16, two different exponential function is obtained that can be used to estimate depth of the formation at 25% porosity.

- Initial Void Porosity

  $y = 479.09e^{-5.581x}$

- CPI Porosity

  $Y = 16090e^{-9.659x}$

By using the function above, the estimated depth obtain when porosity is at 25% are y = 118m for initial void ratio porosity and y = 1438.3 m for CPI porosity. Therefore, it can be concluded that, at depth of 118m up to 1438.3 m the estimated porosity in the area is 25%.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As for the conclusion, the significance of studying the void ratio data for the shallow well environment is to obtain porosity for the particular area and constructed the porosity profile. The void ratio data can be used to calculate both initial void porosity value and CPI porosity value. Both porosity can later be used to construct porosity profile versus depth for reservoir quality estimation. The result obtain can also be further extrapolated and matched with porosity data at deep reservoir interval.

5.2 Recommendation

In order to increase the project accuracy and reliability, the author suggested to:

- Increase more samples collected
- Collect more geological data
- Obtain shallow well pore pressure, thermal conductivity, and thermal gradient to increase the reliability of the reservoir quality estimation.
- In depth analysis of the porosity profile.

CHAPTER SIX

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CHAPTER 7

APPENDICES

A. Gant Chart and Key Milestone (FYP 1)

No.	**Detail/ Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of Project Topic	🟪	🟪												
2	Preliminary Research Work		🟪	🟪	🟪	🟪									
3	Submission of Extended Proposal Defence							🟥							
4	Proposal Defence								🟥						
5	Project work continues									🟪	🟪	🟪	🟪	🟪	🟪
10	Submission of Interim Report														🟥

B. Gant Chart and Key Milestone (FYP 2)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue	🟪	🟪	🟪	🟪	🟪	🟪	🟪							
2	Submission of Progress Report							🟥							
3	Project Work Continues								🟪	🟪	🟪	🟪	🟪		
4	Pre-SEDEX										🟥				
5	Submission of Draft Final Report											🟥			
6	Submission Dissertation (soft bound)												🟥		
7	Submission of Technical Paper												🟥		
8	Viva													🟥	
9	Submission of Project Dissertation (Hard Bound)														🟥

C. Void Ratio Data obtain from the One Dimensional Consolidation Test

Sample Number	Depth Of Sample (m)	Thickness, H (m)	Initial Void Ratio (e_0)	Final Void Ratio (e_f)
BH23	3.45	1.05	3.746	2.163
BH1A (UD1)	3.00	3.00	2.603	1.382
BH1A (UD4)	12.00	3.00	2.456	1.555
BH2A (UD1)	3.00	3.00	2.928	1.522
BH2A (UD3)	9.00	3.00	3.853	1.966
BH4A (UD3)	9.00	3.00	0.714	0.562
BH4A (UD5)	15.00	3.00	0.797	0.637
BH4A (UD7)	21.00	3.00	1.346	1.108
BH4A (UD9)	27.00	1.50	2.547	1.463
BH5A (UD1)	3.00	3.00	2.590	1.406
BH5A (UD4)	12.00	3.00	1.667	1.301
BH2 (UD1)	4.95	1.05	3.179	1.552
BH3 (UD1)	3.45	1.05	2.389	1.508
BH5 (UD1)	3.00	3.00	2.542	1.354
BH5 (UD4)	12.00	3.00	3.142	1.664
BH5 (UD6)	18.00	3.00	1.691	1.335
BH5 (UD8)	24.00	3.00	0.821	0.682
BH8 (UD1)	1.95	1.05	2.944	1.609
BH9 (UD1)	1.95	1.05	2.728	1.523
BH10 (UD1)	3.00	3.00	3.381	1.738
BH10 (UD4)	12.00	3.00	1.002	0.785
BH11 (UD1)	1.95	1.05	2.243	1.287
BH12 (UD1)	3.45	1.05	3.569	2.017
BH13 (UD1)	3.00	3.00	2.376	1.214
BH13 (UD4)	12.00	3.00	3.991	2.161
BH17 (UD1)	1.95	1.05	3.457	2.292

D. Tabulated result of CPI porosity and Porosity Calculation

Sample Number	Depth of Sample (m)	Thickness, H (m)	Initial Void Ratio (e_0)	Changes in Void Ratio,	Ultimate Settlement	CPI	VRF	Porosity	CPI Porosity
BH23	3.45	1.05	3.746	1.583	0.35	1.18	4.75	0.79	0.83
BH1A (UD1)	3.00	3.00	2.603	1.221	1.02	1.34	3.60	0.72	0.78
BH1A (UD4)	12.00	3.00	2.456	0.901	0.78	1.38	3.46	0.71	0.78
BH2A (UD1)	3.00	3.00	2.928	1.406	1.07	1.28	3.94	0.75	0.80
BH2A (UD3)	9.00	3.00	3.853	1.887	1.17	1.17	4.84	0.79	0.83
BH4A (UD3)	9.00	3.00	0.714	0.152	0.27	-1.63	1.73	0.42	0.63
BH4A (UD5)	15.00	3.00	0.797	0.160	0.27	-2.58	1.80	0.44	0.64
BH4A (UD7)	21.00	3.00	1.346	0.238	0.3	2.85	2.33	0.57	0.7
BH4A (UD9)	27.00	1.50	2.547	1.107	0.47	1.35	3.55	0.72	0.78
BH5A (UD1)	3.00	3.00	2.590	1.184	0.99	1.34	3.59	0.72	0.78
BH5A (UD4)	12.00	3.00	1.667	0.366	0.41	1.93	2.68	0.63	0.73
BH2 (UD1)	4.95	1.05	3.179	1.627	0.41	1.24	4.17	0.76	0.81
BH3 (UD1)	3.45	1.05	2.389	0.883	0.27	1.42	3.44	0.70	0.78
BH5 (UD1)	6.00	3.00	2.542	1.188	1.01	1.35	3.54	0.72	0.78
BH5 (UD4)	12.00	3.00	3.142	1.478	1.07	1.24	4.14	0.76	0.81
BH5 (UD6)	18.00	3.00	1.691	0.356	0.4	1.89	2.7	0.63	0.73
BH5 (UD8)	24.00	3.00	0.821	0.139	0.23	-3.08	1.83	0.45	0.65
BH8 (UD1)	1.95	1.05	2.944	1.335	0.36	1.27	3.94	0.75	0.8
BH9 (UD1)	1.95	1.05	2.728	1.205	0.34	1.31	3.74	0.73	0.79
BH10 (UD1)	3.00	3.00	3.381	1.643	1.13	1.21	4.38	0.77	0.81
BH11 (UD1)	1.95	1.05	2.243	0.956	0.31	1.45	3.23	0.69	0.76
BH12 (UD1)	3.45	1.05	3.569	1.552	0.36	1.19	4.57	0.78	0.82
BH13 (UD1)	3.00	3.00	2.376	1.162	1.03	1.41	3.38	0.70	0.77
BH13 (UD4)	12.00	3.00	3.991	1.830	1.10	1.16	4.99	0.80	0.83
BH17 (UD1)	1.95	1.05	3.457	1.165	0.27	1.20	4.45	0.78	0.82

E. Borehole Data use for lithological description.

PROJECT :	**DATE :** 22/4/02-23/4/02	**BH NO :** **BH 26**
LOCATION : P. BUNTING, MUKIM YAN, DAERAH KUALA MUDA, KEDAH	**WATER LEVEL :** NIL	**SHEET NO :** 1 of 1

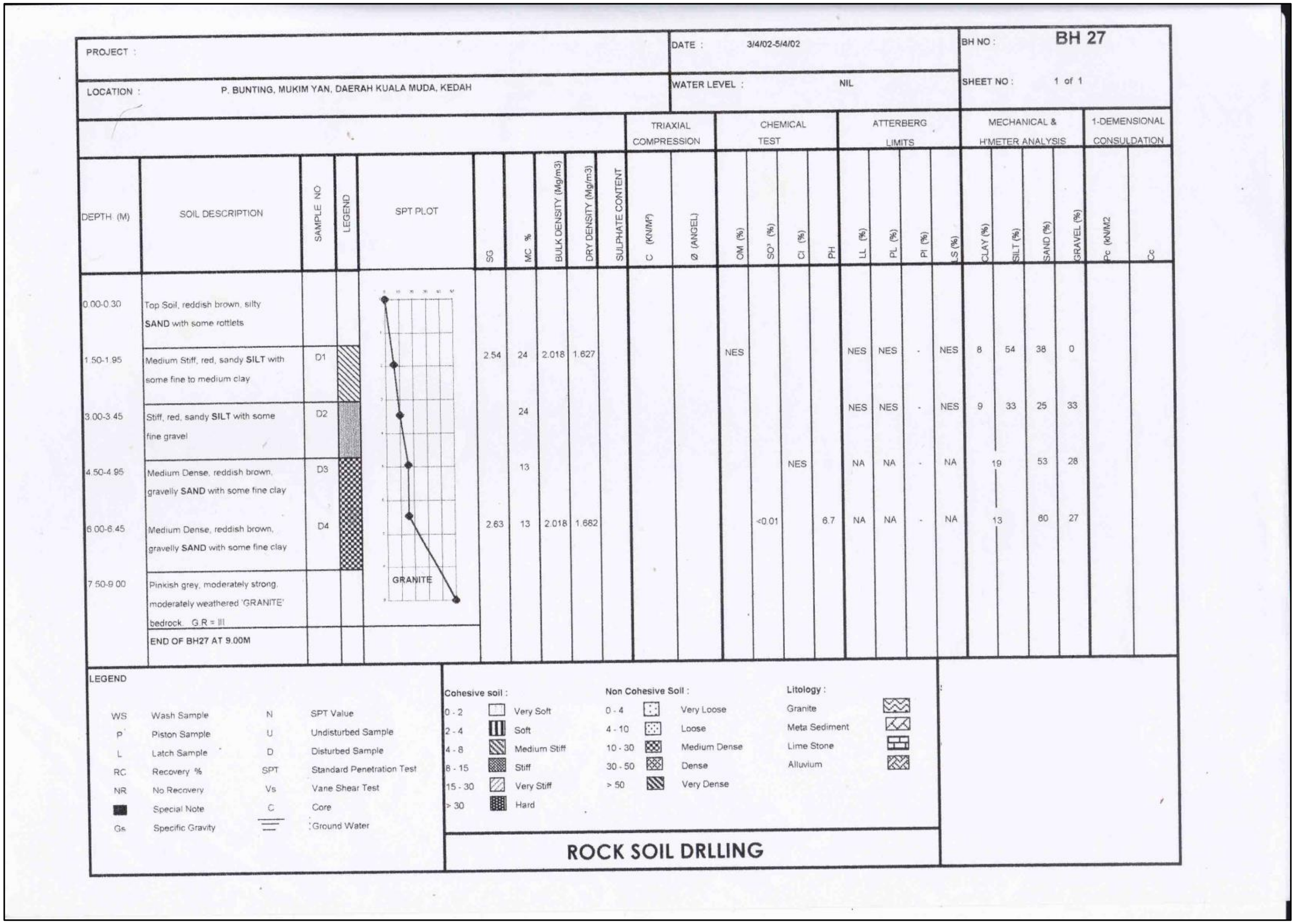
										TRIAXIAL COMPRESSION		CHEMICAL TEST				ATTERBERG LIMITS				MECHANICAL & H'METER ANALYSIS				1-DEMENSIONAL CONSULDATION	
DEPTH (M)	SOIL DESCRIPTION	SAMPLE NO	LEGEND	SPT PLOT	SG	MC %	BULK DENSITY (Mg/m3)	DRY DENSITY (Mg/m3)	SULPHATE CONTENT	C (KN/M^2)	Ø (ANGEL)	OM (%)	SO^3 (%)	Cl (%)	PH	LL (%)	PL (%)	PI (%)	LS (%)	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	Pc (kN/M2	Cc
0.00-0.30	Top Soil, brownish silty **SAND** with some medium to fine gravel																								
1.50-1.95	Medium Dense, reddish brown sandy **GRAVEL** with some clay	D2	▩		2.67	9	1.877	1.722				0.2		0.26		NA	NA	-	NA	14		33	53		
3.00-3.45	Medium Dense, reddish brown, sandy **GRAVEL** with some medium silt and clay	D3	▩		2.66	14							<0.01	0.25		32	26	6	3	8	23	25	44		
4.50-4.84	Very Dense, light grey, sandy **GRAVEL** with some fine clay	D4	▧		2.57	12	1.689	1.508				0.1			6.3	NA	NA	-	NA	3	24	21	52		
6.00-6.45	Very Dense, brownish pale grey silty **SAND** with some medium to fine gravel	D5	▧		2.62	16						0.2	<0.01			29	25	4	2	11	30	39	20		
7.50-9.00	Light grey, yellowish pale grey,moderately strong, moderately weathered **GRANITE** bedrock G.W= II/III			GRANITE																					
	END OF BH 26 AT 9.00M																								

LEGEND

WS	Wash Sample	N	SPT Value
P	Piston Sample	U	Undisturbed Sample
L	Latch Sample	D	Disturbed Sample
RC	Recovery %	SPT	Standard Penetration Test
NR	No Recovery	Vs	Vane Shear Test
■	Special Note	C	Core
Gs	Specific Gravity	≡	Ground Water

Cohesive soil :			**Non Cohesive Soil :**			**Litology :**	
0 - 2	☐	Very Soft	0 - 4	⛶	Very Loose	Granite	▨
2 - 4	▥	Soft	4 - 10	⛶	Loose	Meta Sediment	▨
4 - 8	▧	Medium Stiff	10 - 30	▩	Medium Dense	Lime Stone	▦
8 - 15	▦	Stiff	30 - 50	▩	Dense	Alluvium	▨
15 - 30	▨	Very Stiff	> 50	▧	Very Dense		
> 30	■	Hard					

ROCK SOIL DRILLING



PROJECT :

LOCATION : P. BUNTING, MUKIM YAN, DAERAH KUALA MUDA, KEDAH

DATE : 3/4/02-5/4/02

WATER LEVEL : NIL

BH NO : **BH 27**

SHEET NO : 1 of 1

										TRIAXIAL COMPRESSION		CHEMICAL TEST				ATTERBERG LIMITS				MECHANICAL & H'METER ANALYSIS				1-DEMENSIONAL CONSULDATION	
DEPTH (M)	SOIL DESCRIPTION	SAMPLE NO	LEGEND	SPT PLOT	SG	MC %	BULK DENSITY (Mg/m3)	DRY DENSITY (Mg/m3)	SULPHATE CONTENT	C (KN/M^2)	Ø (ANGEL)	OM (%)	SO^3 (%)	Cl (%)	PH	LL (%)	PL (%)	PI (%)	LS (%)	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	Pc (kN/M2	Cc
0.00-0.30	Top Soil, reddish brown, silty **SAND** with some rottlets																								
1.50-1.95	Medium Stiff, red, sandy **SILT** with some fine to medium clay	D1	▧		2.54	24	2.018	1.627				NES				NES	NES	-	NES	8	54	38	0		
3.00-3.45	Stiff, red, sandy **SILT** with some fine gravel	D2	▦			24										NES	NES	-	NES	9	33	25	33		
4.50-4.95	Medium Dense, reddish brown, gravelly **SAND** with some fine clay	D3	▩			13								NES		NA	NA	-	NA	19		53	28		
6.00-6.45	Medium Dense, reddish brown, gravelly **SAND** with some fine clay	D4	▩		2.63	13	2.018	1.682					<0.01		6.7	NA	NA	-	NA	13		60	27		
7.50-9.00	Pinkish grey, moderately strong, moderately weathered 'GRANITE' bedrock. G.R = III			GRANITE																					
	END OF BH27 AT 9.00M																								

LEGEND

WS	Wash Sample	N	SPT Value
P	Piston Sample	U	Undisturbed Sample
L	Latch Sample	D	Disturbed Sample
RC	Recovery %	SPT	Standard Penetration Test
NR	No Recovery	Vs	Vane Shear Test
■	Special Note	C	Core
Gs	Specific Gravity	≡	Ground Water

Cohesive soil :

0 - 2	☐	Very Soft
2 - 4	▥	Soft
4 - 8	▧	Medium Stiff
8 - 15	▦	Stiff
15 - 30	▨	Very Stiff
> 30	▩	Hard

Non Cohesive Soil :

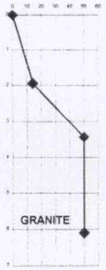
0 - 4	⁘	Very Loose
4 - 10	⁙	Loose
10 - 30	▩	Medium Dense
30 - 50	▦	Dense
> 50	▧	Very Dense

Litology :

Granite	▒
Meta Sediment	▨
Lime Stone	▤
Alluvium	▩

ROCK SOIL DRLLING

PROJECT :		**DATE :** 19/4/02-19/4/02	**BH NO :** **BH 29**
LOCATION :	**P. BUNTING, MUKIM YAN, DAERAH KUALA MUDA, KEDAH**	**WATER LEVEL :** 4.90M	**SHEET NO :** 1 of 1

										TRIAXIAL COMPRESSION		CHEMICAL TEST				ATTERBERG LIMITS				MECHANICAL & H'METER ANALYSIS				1-DEMENSIONAL CONSULDATION	
DEPTH (M)	SOIL DESCRIPTION	SAMPLE NO	LEGEND	SPT PLOT	SG	MC %	BULK DENSITY (Mg/m3)	DRY DENSITY (Mg/m3)	SULPHATE CONTENT	C (KN/M^2)	Ø (ANGEL)	OM (%)	SO^3 (%)	Cl (%)	PH	LL (%)	PL (%)	PI (%)	LS (%)	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	Pc (kN/M2	Cc
0.00-0.30	Top Soil, brown, silty **SAND** with some fine gravel																								
1.50-1.95	Medium Dense, brownish grey, sandy **GRAVEL** with some fine clay	D2	▨ ▩			14										31	25	6	3	13	24	28	35		
3.00-3.43	Very Dense, brownish, grey, silty **SAND** with some fine gravel	D3	▨			12	1.982	1.770						0.08		NA	NA	-	NA	19		64	17		
4.50-6.10	Yellowish grey,.moderately strong, moderately weathered 'GRANITE'																								
	END OF BH 29 AT 6.10M																								

LEGEND

WS	Wash Sample	N	SPT Value
P	Piston Sample	U	Undisturbed Sample
L	Latch Sample	D	Disturbed Sample
RC	Recovery %	SPT	Standard Penetration Test
NR	No Recovery	Vs	Vane Shear Test
■	Special Note	C	Core
Gs	Specific Gravity	≡	Ground Water

Cohesive soil :			**Non Cohesive Soil :**			**Litology :**	
0 - 2	☐	Very Soft	0 - 4	⁘	Very Loose	Granite	▨
2 - 4	▥	Soft	4 - 10	⁙	Loose	Meta Sediment	▨
4 - 8	▧	Medium Stiff	10 - 30	▩	Medium Dense	Lime Stone	▤
8 - 15	▦	Stiff	30 - 50	▩	Dense	Alluvium	▨
15 - 30	▨	Very Stiff	> 50	▧	Very Dense		
> 30	■	Hard					

ROCK SOIL DRLLING