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JANUARY 2012

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

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JANUARY2012

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Facies and Reservoir Characteristics of Cross-Bedded and Plane-Bedded Sandstone

by

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

JANUARY 2012

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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 original work contained herein have not been undertaken or done by unspecified sources or persons.

AZRI HARIZ BIN ABDUL RAOF

ABSTRACT

Analysis of sedimentary and petrophysic properties for outcrops at Nyalau Formation were carried out to establish its geological and reservoir qualities. This was done with respect to the fact that most onshore geological formations nearby substantial hydrocarbon sources are studied for better delineation of the basin (Joanna M. Ajdukiewicz, 2010). Consequently cross-bedded structure has always represented a large fraction of sandstone reservoirs (M.E. Lord, 1989). At the geological site, various sedimentary properties are inferred individually for each beds. Such properties are then associated with facies model to define its depositional environment. Identification of these features requires skilled observations and measurements to be carried out at the outcrop; example includes dip-angle, lamina thickness, colour, mineralogy, and preliminary grain sorting. Besides these properties, sandstone distribution and lithology must also be recognized for bedforms fair sample size (D. Mikes, 2003).

Moving on, samples are tested at lab facilities for sedimentary properties and petrophysic (Franz, 1985). Among the relevant test to be made are grain size / sorting test, porosity test (digital helium porosimeter), permeability test (multi-phase flow permeametry) Due to lack of time and resources, bed and boundary effects as well as heterogeneities effect are neglected, only focusing on the clean, most homogeneous sandstone sample available. The result for petrology was however inconclusive due to erroneous sample, allowing only facies model analysed linked with permeability qualities from mathematical correlation. Finally, the outcome was made in terms of reservoir qualities established as Good for both site studied. Conclusively the Samling outcrop offers a very good facies for sandstone reservoir formation due to clean HCS bed as well as wavy laminated sandstone. Its boundaries are often shale-mudstone or heterolithic which will become the no-flow trap. As for Kg Sg Plan, the outcrop has thicker clean sandstone layer. Another sandstone layer has mud clast heterogeneities thus will definitely hamper flow properties. It is therefore important to distinguish the heterogeneities and the continuity of the clean sandstone bed with respect to other potential no-flow zones.

ACKNOWLEDGEMENT

The Author would like to thank my Supervisor, Assoc Prof Dr Abdul Hadi Abd Rahman whose guidance and direction help steer this project. I am also honoured to have Dr Hadi as my trainer in the field of geology during field trip especially his tireless discourse on sedimentary structure identification as well as depositional environment analysis. Apart from that, I extend my heartfelt gratitude to my colleague Aiman Ajmal for his support and managing the laboratory schedule. Furthermore, I would like to express my gratitude to the postgraduate student Zaini who had also taught me and my colleague during the field trip. Consequently I would like to thank Geoscience Laboratory Technicians whom had guided us in laboratory analysis as well as providing equipment for the field trip. Last but not least, I acknowledge the care made by my close family and friends such as my parents, Syahir, Syafiq and Ben for their continuous support.

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CHAPTER 1: INTRODUCTION

i. Background Information

Sandstone reservoirs remained as a prolific oil & gas source due to higher recovery factor (BP Statistical Review 2006). The sandstone at Nyalau Formation has been studied by several researchers before (Mazlan Madon, 2007), (Teoh Ying Jia, 2009). It is dominated by shallow marine, coastal and intertidal facies (Mazlan Madon, 2007); making it ideal for sandstone geological research project.

ii. Problem Statement

Sedimentary and petrophysical properties of several sandstone outcrop in Nyalau Formation is not available to properly assess facies and reservoir characteristics..

iii. Problem Identification

The outcrop in Bintulu requires in-depth assessment to prove its significance towards the oil & gas industry surrounding the area.

iv. Objective

a) To investigate and determine facies characteristics and reservoir quality of sandstone.
b) To establish a relationship between the facies characteristics and reservoir quality of the formation.

v. Purpose

a) To understand basic geological formation features of sandstones.
b) To investigate stratification and lithology of the outcrop.
c) To practice correct method of field measurements; alongside laboratory work and analysis.
d) To categorize lithofacies and develop depositional model.
e) To establish relationship between facies sedimentological characteristics with reservoir quality properties.

vi. Scope of Work

a) Field sedimentological measurements and collection of samples.
b) Laboratory analysis of sedimentology properties and features.
c) Laboratory analysis of petrophysical properties.

vii. Significance

a) This research would complement other current available researches at Nyalau Formation and promote the significance of its reservoir qualities for the Oil & Gas industry.

viii. Relevance

Complements and further enhance my understanding from previous courses such as Reservoir Rock & Fluid Properties and Introduction to Petroleum Geoscience.

ix. Feasibility

The whole research should be completed within 6 months (October 2011 – April 2012) and is indeed achievable based on current progress and planned future.

CHAPTER 2: LITERATURE REVIEW

2.1 : Sandstone

Clastic sediments are the building blocks of sandstone. Migration and deposition of grains are followed by lithification to form sedimentary rocks (Tucker, 2001). All of these phases are brought about by wind or water from continental, rivers, rain and sea to form sandstone (LeBlanc, 1973). The preservation of structures and textures in the sediments are the fundamental approach in facies analysis. Different facies occurring together are common as such termed as facies associations or facies assemblages (Cheel, 2005). In general, sandstone formations are generally categorized into cross-bedded and plane-bedded types with various degree of maturity (Figure 4). Cross-bedded sandstones have dips inclined angularly to the overall stratification formation while plane-bedded strata are parallel to the overall formation (Coordinator, 2006).

Knowledge about visible sedimentary structures are important for subsurface stratigraphy studies in oil & gas due to the fact that such geological formation always transmit to one another with numerous geological changes (Shirley P.Dutton, 2003). Sandstone identification and features should be recognized in a proper technique to avoid misrepresentation and erroneous data. The first step would be to ascertain planar surfaces in which strike and dip measurements are made. Then bed thickness should be thoroughly investigated; fulfilling minimum, maximum and modal thickness if available. If the bed is structureless, it should be cleaned and examined carefully under hand lens. Moving on, grain size and morphology can be investigated with a comparator chart and hand lens. Any sediment fabric should also be observed such as grain orientation and fossils. A further view should be made to fully cover the trends of the outcrop such as erosional structures, cross-lamination, slumps/slides, and faults. Finally a close-up investigation should be made to ascertain its minerals, colour, and find any bioturbation if any ((A.V.Stow, 2005).

2.2 : Field Data Measurement and Records Technique

The aim of the field work is to measure and record data then collect enough rock samples to be assessed in laboratory. There are many properties which will be investigated. Each of these is equally important in determining the major lithofacies. Careful observation and correct technique will be practice to ensure data integrity. The data recorded includes details as below:

- **a) Strike and dip :** strike is the bearing of horizontal line on the planar surface while dip is the angle from the horizontal of maximum slope
- **b) Bed thickness :** minimum and maximum thickness in cm
- **c) Bed geometry :** scale, continuity (Figure 3)
- **d) Bed boundaries :** sharpness / distinctiveness of contacts
- **e) Grain size :** sandstone should exhibit between 0.063 to 2mm (Figure 1)
- **f) Grain morphology :** shape, orientation and sorting
- **g) Composition :** minerals, organic material, rock fragments, cement material
- **h) Colour :** comparison with Munsell Soil / Rock Colour Chart (Figure 2)
- **i) Erosional features :** unconformities, channel
- **j) Sedimentary Structures :** stratification, deformation such as slide / slump

(A.V.Stow, 2005)

In order to obtain these data, correct drawings symbol of graphic log section (Figure 5) alongside several tools and charts are required among which include:

- **a) Geological hammer:** crush rock
- **b) Compass clinometer:** measure dip / strike angle
- **c) Hand lens:** close-up observation
- **d) Penknife:** to carefully observe grains
- **e) Measurement tape:** measure length of bed, thickness
- **f) Camera:** pictures of formation
- **g) Portable GPS:** pinpoint position of location
- **h) Grain size chart:** preliminary grain size
- **i) Rock Colour Chart:** rock colour
- **j) Coloured marker pens:** drawing topography map, lithology, and section log
- **k) Rock sample material:** plastic wrap and box for storage

(Tucker, 2001)

Apart from bedding and lamination arrangements, there are many sedimentary structures in sandstone which can be identified with clear-cut feature as below:

a) Ripple: formed by wave or tidal action
b) Flute: fluid erosion without obstacles
c) Hummocky cross-stratification (HCS): medium-scale cross-bed (>10cm<1m)
d) Load and Flame: differential sinking of one bed into another
e) Slump: internal folding due to external factor
f) Wedge: tapering thin of an extension of formation due to high pressure
g) Crack: infill into cavities formed in lithification
h) Stylolite: irregular dissolution surfaces with insoluble residue
i) Liesegang rings: very thin chemical colour banding usually iron oxides

(A.V.Stow, 2005)

2.3 : Sedimentology Laboratory Assessment

Upon completion of field work, rock samples collected will be brought into the sedimentology laboratory to assess further properties which include:

a) Grain sorting: Using sieves and sieve shaker (results as Figure 7)
b) Mineralogy: Using microscope
c) Texture: After cleaning the rock, use microscope (Tucker, 2001)

2.4 : Classification of Facies

Based on the accumulated data of the outcrop's sedimentary properties, we categorize the available data according to the distinguished sections of similar sediments. These are then numbered and further classified to its depositional process to form facies. Finally microfacies can be deduced if we can interpret the facies based on depositional environment. Data's quality and reliability in representing the outcrop is important to ascertain the depositional environment. Interpretation is a diagnostic approach (A.V.Stow, 2005). Having a clear steps in establishing facies are important to avoid mistake. There are two approach; The Forward Problem and The Inverse Problem. In the former, flow conditions are determined corresponding to the bed configuration which would then be associated with the stratification. As for the latter, stratification is studied first to establish the bed configuration and then correlated against potential flow conditions. The Inverse way is difficult and could be erroneous due to no information of time and the changes which has happened to the formation. Hence, The Forward Problem will be used to establish the bed configuration and depositional flow conditions (Mikes, 2003). According to A.V.Stow, 2005, the simplest method is with 3 steps as below:

a) **Lateral trends and geometry :** by careful correlation of same intervals over large area
b) **Architectural elements and facies associations:** linking small and medium scale sequences, trends,sequence boundaries and geometry into natural architectural element. Example include erosive base for deep-water channel.
c) **Sequence stratigraphy and bounding surfaces:** parallel system fitted to depositional units with chronostratigraphic sequence (Figure 6).

2.4 : Petrophysic Laboratory Assessment

Reservoir quality properties will be tested upon 3 rock samples for porosity and permeability. Due to time constraint and software unavailability, X-Ray tomography, also known as a CT-scan providing 3D imaging of the rock ((Sevcan Kurum, 2009) will not be performed. Therefore, the author had to cancel simulation flow for flow-cell modelling. Consequently it was found that realistic flow simulation requires larger sample size across wider coverage area to be significant (D. Mikes, 2003). Thus it is sufficient that the parameters measured for petrography is porosity and permeability. The equipment that will be used for petrography includes:

a) Helium Porosimeter
b) Permeameter

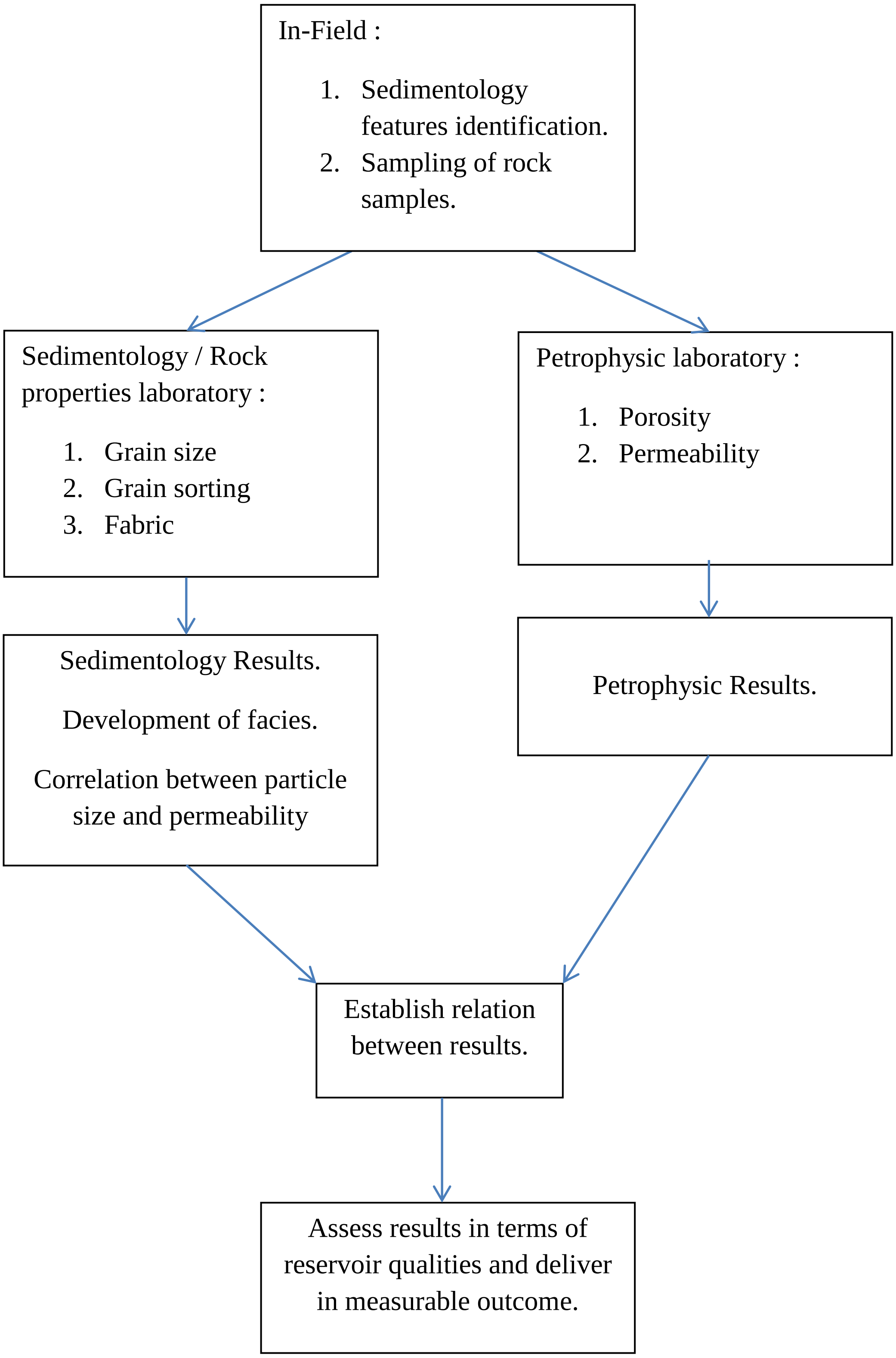
From the measurements, data available for analysis includes:

a) Permeability: measurement of rock's ability to transmit fluid, in mD
b) Pore volume: volume of rock with capacity to store fluids
c) Klinkenberg factor: gas slippage effect affecting permeability measurement
d) Grain density: density of rock grain
e) Grain volume: volume of rock's grain

The data for grain volume and density was erroneous, making the porosity / permeability qualities unreliable. Further assessment using mercury porosimeter requires a cubic-shaped rock unit which was not possible due to the friable unconsolidated rock for Kg Sg Plan site. Eventually, these results from sedimentology and petrography are linked together to establish the significance of the formation's reservoir qualities. Due to time constraint, the delineation and bedforms permeability effect towards flow are neglected (Meyer, 2002). Measurements made will be for both vertical and horizontal flowboth in X and Y axis). In addition to that, correlations between the sedimentary facies with reservoir qualities is made based on the facies of the rock sample used which should be mainly clean sandstone without significant heterogeneities, hence not covering the whole lithofacies category.

CHAPTER 3

3.1: RESEARCH METHODOLOGY



3.2: PROJECT ACTIVITIES

Throughout the commencement of this research project in October 2011, over 5 months was spent on reading relevant materials. Over 20 related journals and 5 books mainly focusing on sandstone, Borneo's geological formation, Sedimentary Rocks, Petrography, and Basin Analysis was studied. After much deliberation and planning, the field trip to Bintulu was successfully done from 24th to 27th February 2012. Since it is important for me to learn through the eyes of an expert, the trip was participated by my colleague, 2 postgraduate students and my Supervisor, Assoc. Professor Dr. Abdul Hadi Abd Rahman.

Our field trip was fruitful, with 7 outcrop sites visited in total while investigation was done in 5 sites. Below are the outcrop site investigated with general information.

1. Sungai Mas at N 03°04'55.4" / E 112°59'36.2"
2. Samling Estate at N 03°04'07.9" / E 113°00'31.3"
3. Telekom Beach at N 03°18'55.9" / E 113°07'06.0"
4. Kg. Sg. Plan at N 03°15'58.9" / E 113°06'42.3"
5. Tg. Kidurong at N 03°15'35.8" / E 113°06'18.3"

The first laboratory assessment was made on 16th March 2012 for grain size analysis. Next, me and my colleague started petrology laboratory analysis by preparing sample. Several samples were successfully cored for analysis with poro-perm tabletop equipment. On the other hand, Samling and Kg Sg Plan samples were too young and uncemented. Therefore we opted for mercury porosimeter assessment which was made for all other site samples too. However, Kg Sg Plan sample was broken down beyond the minimum size for mercury injection thus making it impossible to test. Consequently we made permeability estimation via mathematical correlation as suggested by Dr. Lutz Riepe and Dr. Chow Weng Sum.

3.3: KEY MILESTONE

Due to the extensive geological investigation in this research, the field trip holds a significant impact towards the outcome. In addition, this research's simple research methodology calls for equal importance among both sedimentary properties and reservoir qualities. It is therefore incumbent to establish key milestone to ensure reliability of data obtained as well as thorough analysis at each stage. The key milestone achieved includes:

1. Completed literature review especially for sedimentary rocks in the field as well as petrography methodologies.

2. Field trip to outcrop in Bintulu for in-field studies.

3. Geotechnical laboratory for grain size analysis.

Detailed sedimentology properties assessment such as mineralogy and petrology properties was made after data gathering was completed. Based upon the weighted workload of each milestone, the project was delayed but remains feasible within the timeframe of this research duration.

Results for each of the completed milestone are presented in this report alongside pictures of the respective outcrop site. Based on the field studies, several geological facies was ascertained and logged vertically to infer changes in depositional environment. However, due to lack of time to investigate further parameters such as biogenic properties, total organic compound, and x-ray diffraction; depositional environment cannot be inferred conclusively. Instead, changes in environment are only made with probable suggestions based on preliminary in-field studies.

3.4: PROGRESS CHART

UTP January 2012 Semester Week				1	2	3	4	5	6	9	1	11	12	13	14	15
Month				Jan	February				March						April	
Task / Activities	**Duration**	**Start**	**Finish**	23-28	30-4	6-11	13-18	20-25	27-2	30-4	5-10	12-17	19-24	26-31	2-7	9-14
Commencement																
FYP Briefing (II)	1 day	6/2	6/2													
Literature Review	Everyday															
Progress Report	20 days	10/2	16/3													
Field & Lab Work																
Site Visit	1 week	24/2	27/2													
Collection and Storage	2 days	3/3	4/4													
Laboratory Analysis	1 month	13/3	24/3													
Results	2 months	13/3	13/4													
Deliverables																
Poster Presentation	2 weeks	19/3	2/4													
SEDEX	4 days	9/4	12/4													
External Examiner	1 day	13/4	13/4													
VIVA Presentation	1 day	23/4	23/4													
Final Report	1 month	7/4	9/5													

Submission Due / Attendance

3.5: THEORY

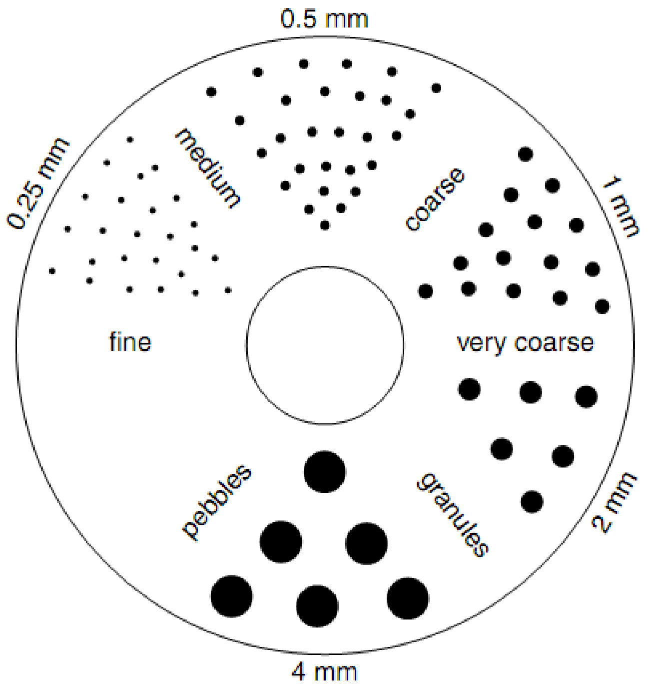


Figure 1 : Grain Size Chart (A.V.Stow, 2005)

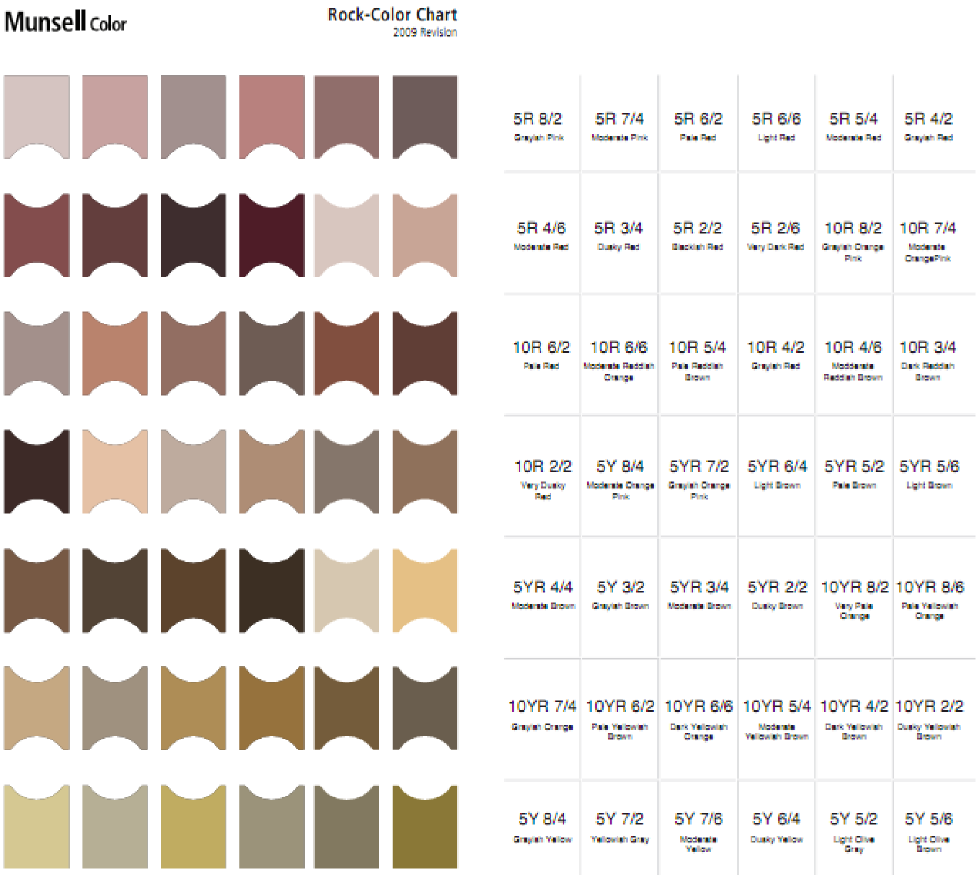


Figure 2 : Rock Colour Chart (Shirley P.Dutton, 2003)

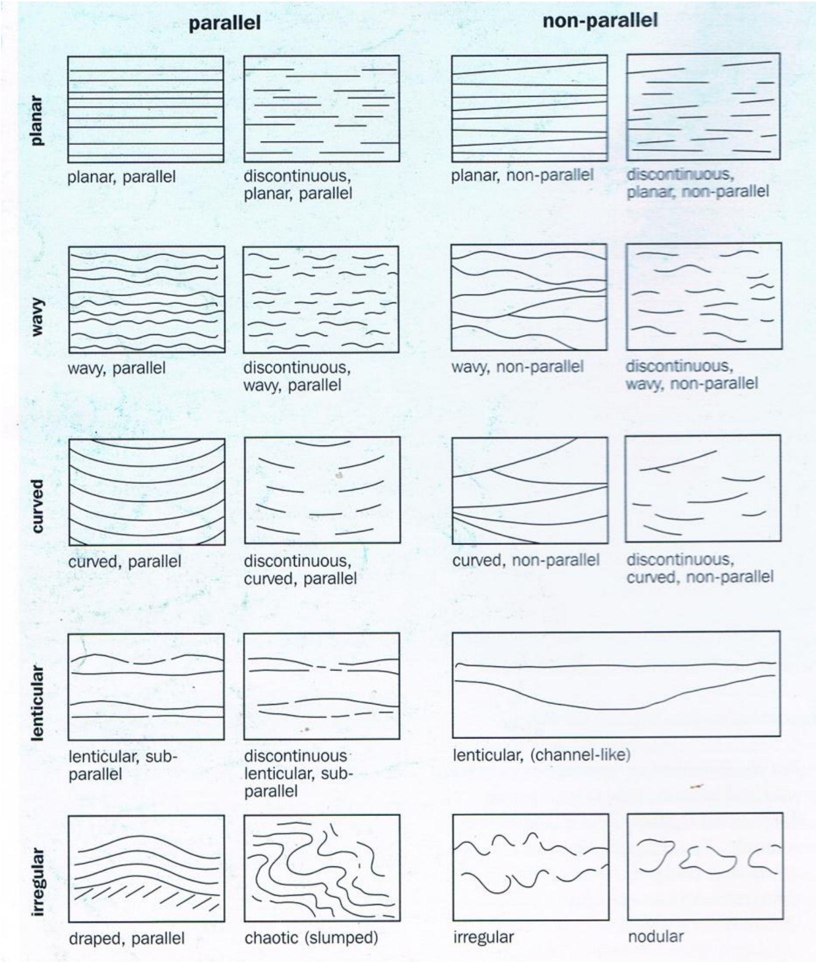


Figure 3 : Bedding and lamination geometry (A.V.Stow, 2005)

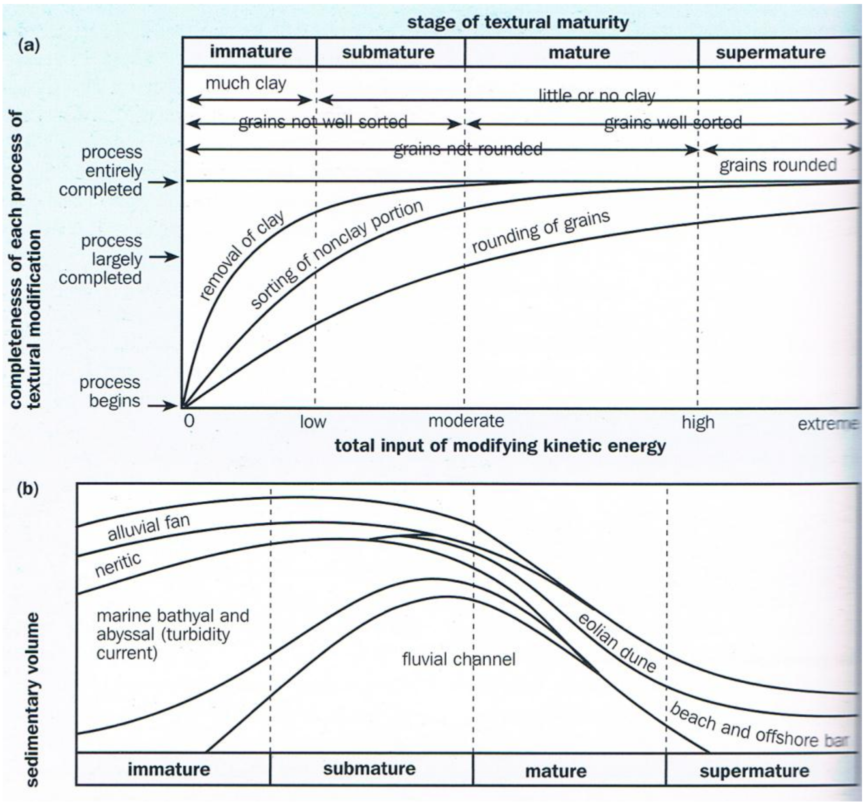


Figure 4 : Sandstone textural maturity (A.V.Stow, 2005)

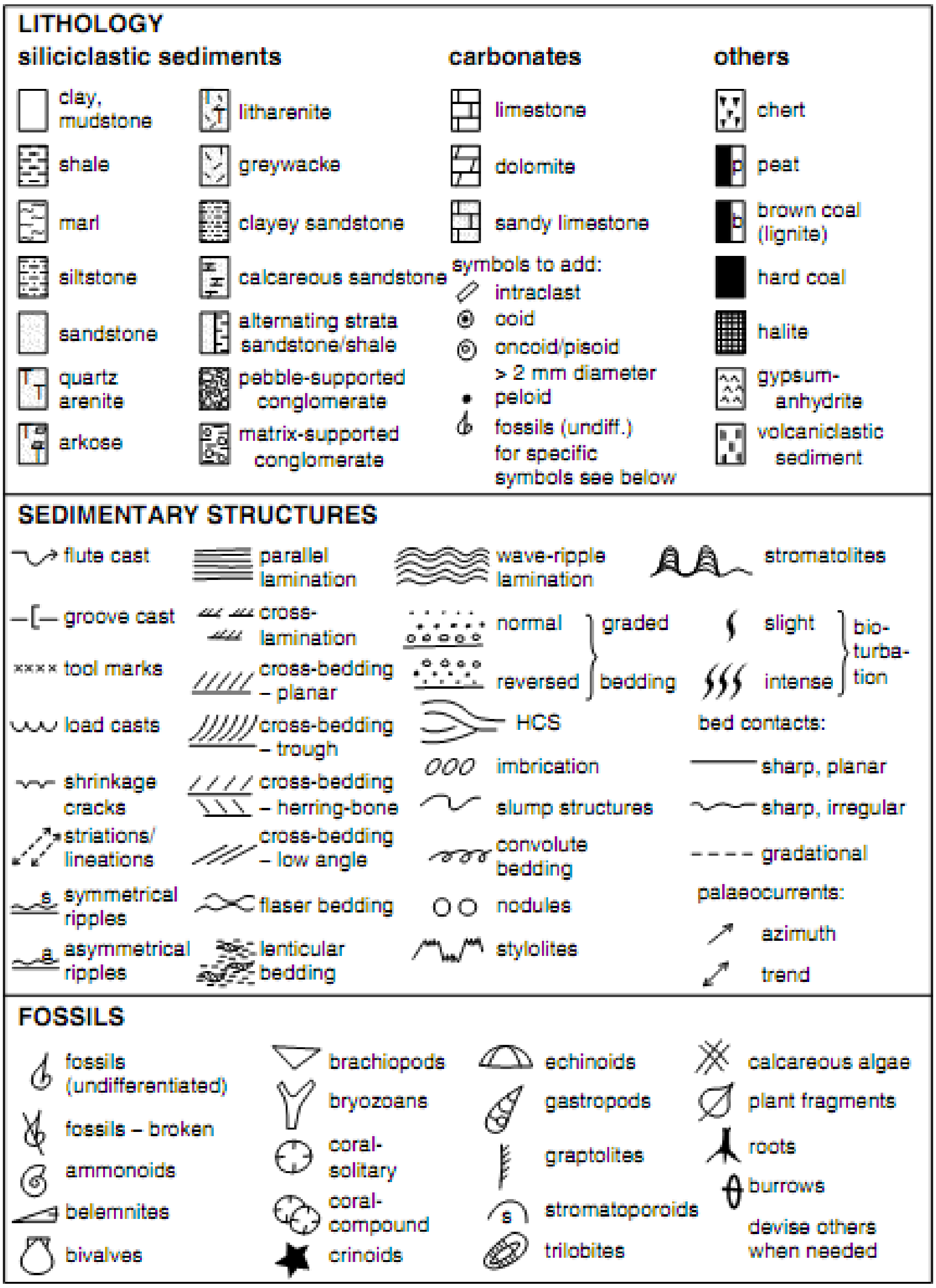


Figure 5 : Symbols for lithology, sedimentary structures,and fossils for graphic log
(Tucker, 2001)

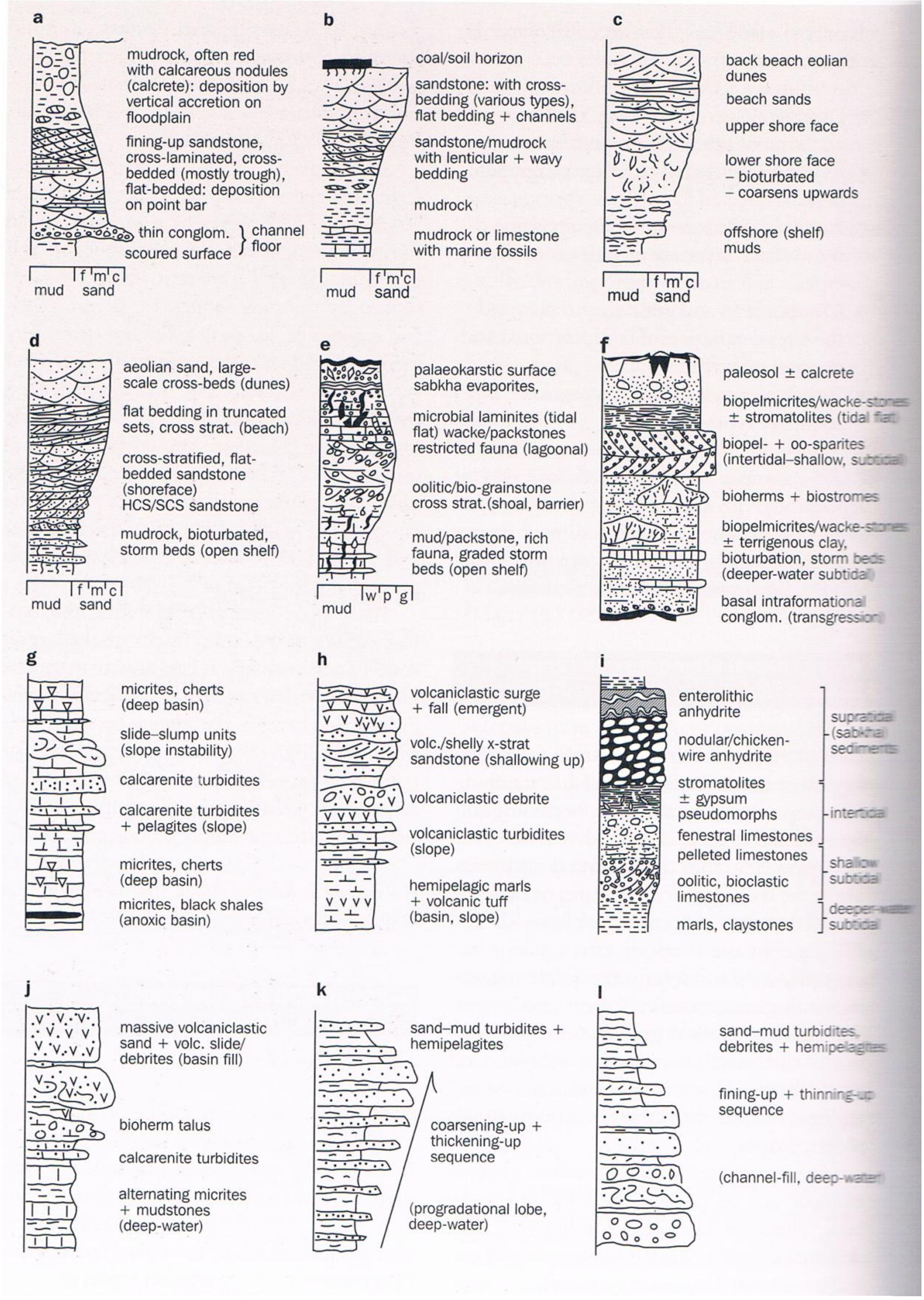


Figure 6 : Chronostratigraphic sequence model for facies interpretation
(A.V.Stow, 2005)

CHAPTER 4: RESULTS & DISCUSSION

4.1: SEDIMENTARY FEATURES

By carefully using the methods by (A.V.Stow, 2005) and also facies character from (Yuniarti Ulfa, 2009), I was able to assess the visible formation features and differentiate between weathering effects and sedimentary structures, as well as make facies analysis for 2 outcrops studied. Below are several pictures, showing visible sedimentary structures as well as different types of rocks found.

.

Figure 7 : Parallel mudstones interlayered by wavy sandstone layers at Telekom Beach. Closer view shows very fine cross-bedding within the sandstone layer.

Figure 8 : Wavy irregularly parallel laminated sandstone at Samling Estate

Figure 9 : Hummocky Cross-lamination visible at the left side of the Telekom Beach outcrop .

Figure 10 : Intense bioturbation at Kg. Sg. Plan outcrop .

Figure 11 : Very clean structureless sandstone layer above rippled sandstone-heterolithic at Kg. Sg. Plan outcrop .

Figure 12 : Distinct ripple structure seen below the coin at Taman Jasa Putra Jaya outcrop .

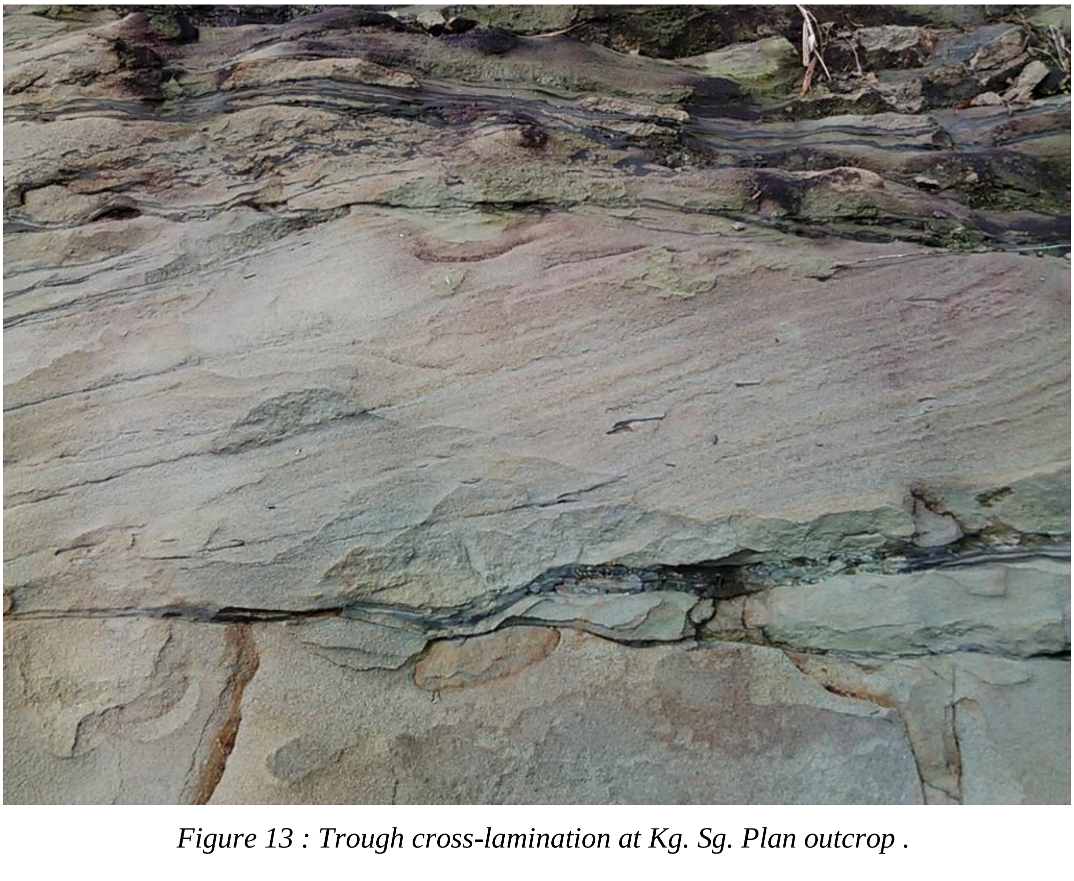
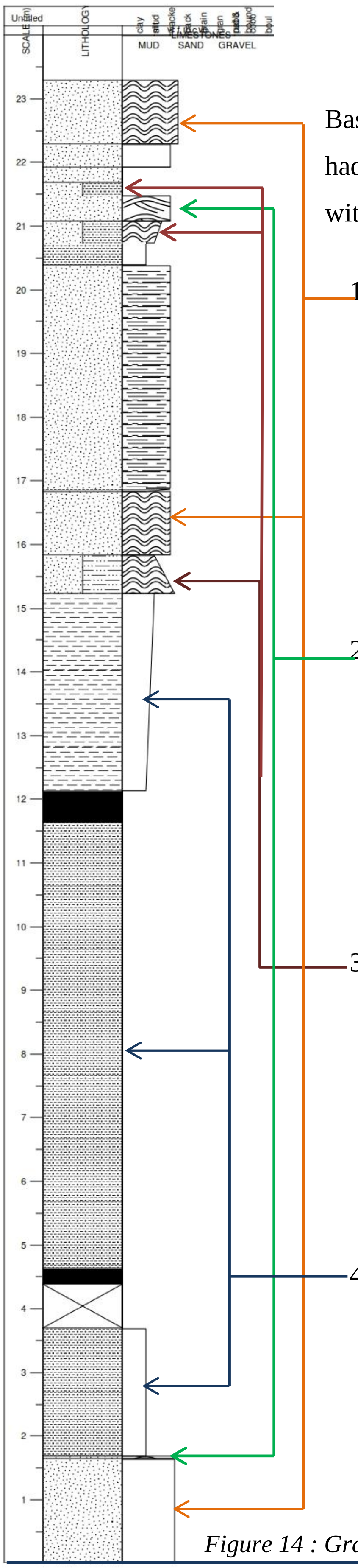


Figure 13 : Trough cross-lamination at Kg. Sg. Plan outcrop .

4.2: FACIES ANALYSIS: Samling Estate Outcrop.



Based on the vertical log recorded, the author had divided the facies to several categories with their colour as follows:

1. Internally wavy cross-laminated bioturbated sandstone.
   - This facies are the major one at the outcrop with layers ranging from 25cm to 350cm.
   - Intense bioturbation with traces of *ophiomorpha*.

2. Hummocky-cross-stratification sandstone.
   - Facies thickness ranges from 5cm to 40cm.
   - Mostly low angle with wavy lamination.

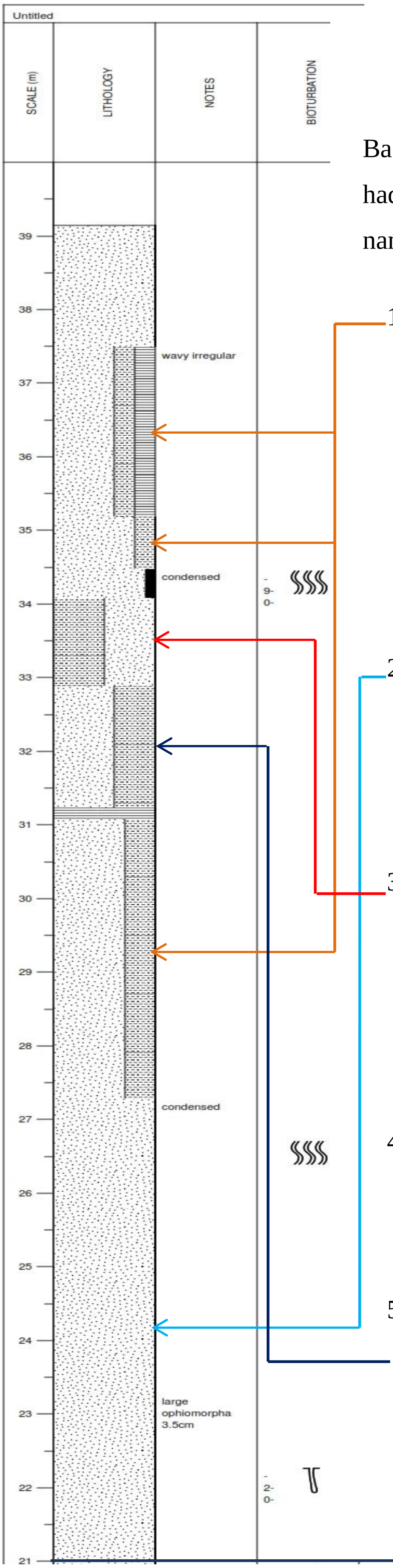
3. Sandy heterolithic.
   - Thickness range from 5cm to 60cm.
   - Preliminary grain size estimation <0.5mm.
   - Some layers exhibit wavy ripple structure.

4. Shale-mudstone
   - Very thick with range starting from 200cm to 310cm.
   - Dominant on the lower part of the outcrop.

Figure 14 : Graphic log of Samling Estate outcrop .

4.3: INTERPRETATION: Samling Estate Outcrop

Based on the vertical log of Samling Estate, hummocky cross-stratification are indicative of storm weather which shows that it is at lower to middle shoreface. Layers of mudstone and shale on the other hand prove alternating energy level in water flow, from storm to fairly strong wave to create such assemblages. Furthermore, sandy heterolithic may indicate middle shore face nearer to the coast, where enough amount of sands are washed away then deposited with mud and silt. Moreover, intense bioturbation within the wavy cross-laminated sandstone represents shallow marine environment being created successively after layers of mudstones and heterolithic. This upward succession of layers shows regression, a decline in sea level as the sea bed rises from lower shore face to middle shore face where sands are deposited and marine life thriving. Detailed analysis shows that the hummocky cross-stratification was formed once more after the regression process, indicating that there was a rise in sea level; transgression. This facies was layered in the middle between two thin heterolithic layers. This showed a very sudden increase in sea level over a short period of time evidently shown by the thin layer. Besides that, the sandstone layer at the bottom being overlayed by mudstone shows that the transgression, regression process might be cyclical. However, inferring the forces causing this cycle is beyond the scope of this research. Additionally, the 2 coal bed formed is an indication of huge plant deposits, which is normally in swamp environment. The mudstone above the coal bed may indicate transgression or sudden flooding. Finally, the gradual thinning of heterolithic layers as well as thicker sandstone bed upwards shows an overall decline in sea level.



4.4: FACIES ANALYSIS: Kg. Sg. Plan Outcrop.

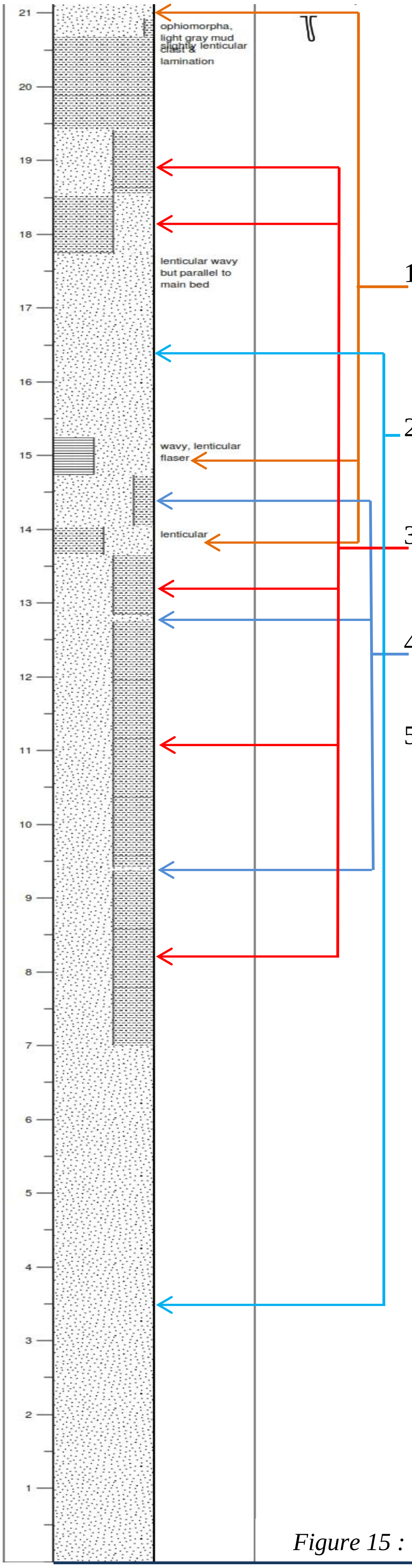
Based on the vertical log recorded, the author had divided the facies to several categories namely as follows:

1. Flaser slightly lenticular sandstone interbedded with light gray mud.
   - This is the primary sandstone layer with thickness from 20 to 250cm.
   - Some parts contain massive mud clasts and lamination.
   - Moderate bioturbation
2. Very clean sandstone.
   - Intense bioturbation with traces of large size *ophiomorpha*..
   - Thickness range from 3 to 70cm..
3. Muddy heterolithic.
   - Thickness range from 80 to 330cm.
   - Primarily mud and shale with normal grading.
   - Sand layers are rippled.
4. Ripple-top sandstone
   - Very thin with range 3 to 70cm.
   - Usually bounded by heterolithic.
5. Low angle cross-laminated sandstone with mudstone interval.
   - Lamination varies from tabular to trough cross-lamination (165cm).

continue on next page .

(continued)

FACIES ANALYSIS:
Kg. Sg. Plan Outcrop.



1. Flaser slightly lenticular sandstone interbedded with light gray mud.
2. Very clean sandstone.
3. Muddy heterolithic.
4. Ripple-top sandstone
5. Low angle cross-laminated sandstone with mudstone interval.

Figure 15 : Graphic log of Kg. Sg. Plan outcrop .

4.5: INTERPRETATION: Kg. Sg. Plan Outcrop

Based on the vertical log of Kg. Sg. Plan, wavy lenticular sandstone interbedded with mud lamination and clasts are the dominant facies. This facies can be formed in tidal flats where the tidal rhythm and current plays with alternating water flow moving upstream and downstream. This creates different mixture of deposition with sand dominating downstream current towards the sea while mud dominates upstream tidal current. Since most of the lenticular beds contain more sand with mud lamination and clasts, it can be said that the environment is fluvial dominated delta, with possibility of the river cutting through the delta; eroding sand away then depositing them further seaward.

Observation from bottom shows that the clean sand was overlaid by alternating layers of muddy heterolithic and ripple-top sandstone. This indicates that the environment changes to a tidal-dominated shore most probably due to transgression. The rippled sandstone formed during low tide whereas the heterolithic during high tide.

Moderate to intense bioturbation such as *ophiomorpha* was found at sandstone layers indicating shallow marine environment ideal for marine life. In addition to that, slight cross-lamination sandstone was found above very thin shale bed represents high energy environment probably due to storm events. Moreover, there were 2 condense sandstone section, proving that the environment is thriving with marine life.

4.6: SEDIMENTARY PROPERTIES-GRAIN SIZE ANALYSIS

Based on sample availability, there were 4 sample tested for grain size analysis each from different location at Geotechnical Laboratory 2 Block 14 on 16th March 2012. The results are tabulated as below:

4.6.1 Sungai Mas

Sieve Size	Mass Sieve with Sand	Mass Empty Sieve	Mass of Sand	Cumulative Mass of Sand	Mass Percentage	Cumulative Mass Passing each Sieve
µm/mm	gm	gm	gm	gm	%	%
2.00mm	602.38	469.00	133.38	133.38	15.98	84.02
1.18mm	502.52	435.74	66.78	200.16	23.98	76.02
600µm	463.63	403.14	60.49	260.65	31.23	68.77
425µm	762.45	378.89	383.56	644.21	77.19	22.81
300µm	481.90	371.15	110.75	754.96	90.45	9.55
212µm	349.60	344.94	4.66	759.62	91.01	8.99
150µm	390.21	333.46	56.75	816.37	97.81	2.19
Bottom Pan	411.86	393.60	18.26	834.63	100.00	0.00

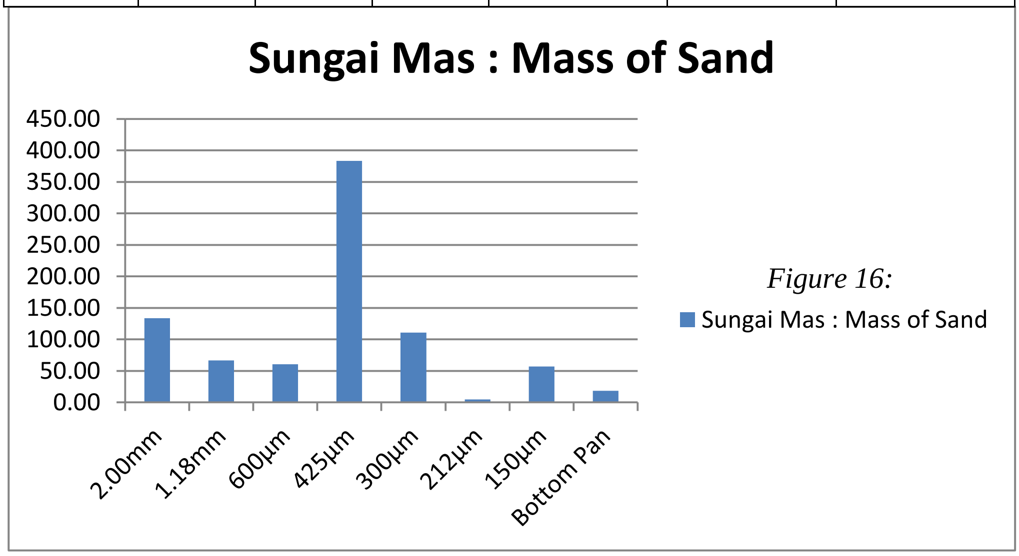


Figure 16:

4.6.2 Samling Estate

Sieve Size	Mass Sieve with Sand	Mass Empty Sieve	Mass of Sand	Cumulative Mass of Sand	Mass Percentage	Cumulative Mass Passing each Sieve
µm/mm	gm	gm	gm	gm	%	%
2.00mm	472.96	470.65	2.31	2.31	0.46	99.72
1.18mm	438.52	434.60	3.92	6.23	1.25	99.25
600µm	424.94	405.63	19.31	25.54	5.11	96.94
425µm	383.13	366.93	16.20	41.74	8.36	95.00
300µm	410.37	357.65	52.72	94.46	18.91	88.68
212µm	536.15	341.15	195.00	289.46	57.95	65.32
150µm	506.68	347.12	159.56	449.02	89.90	46.20
Bottom Pan	444.04	393.60	50.44	499.46	100.00	40.16

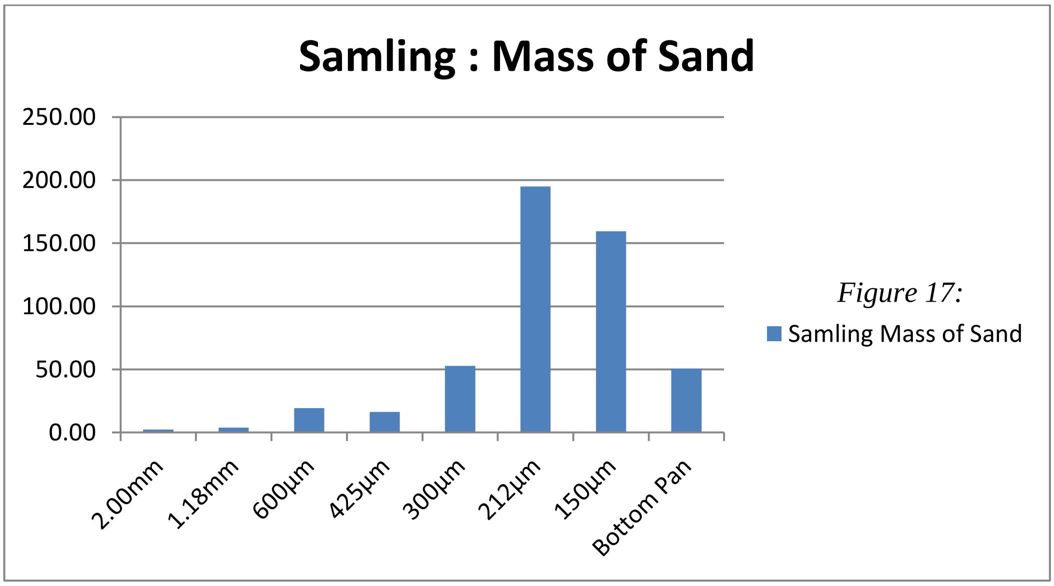


Figure 17:

4.6.3 Kg. Sg. Plan

Sieve Size	Mass Sieve with Sand	Mass Empty Sieve	Mass of Sand	Cumulative Mass of Sand	Mass Percentage	Cumulative Mass Passing each Sieve
µm/mm	gm	gm	gm	gm	%	%
2.00mm	516.26	470.64	45.62	45.62	9.16	94.53
1.18mm	469.21	434.59	34.62	80.24	16.12	90.39
600µm	449.24	405.55	43.69	123.93	24.90	85.15
425µm	408.93	366.80	42.13	166.06	33.36	80.10
300µm	493.11	357.43	135.68	301.74	60.61	63.85
212µm	479.66	341.12	138.54	440.28	88.45	47.25
150µm	384.63	347.00	37.63	477.91	96.00	42.74
Bottom Pan	413.52	393.63	19.89	497.80	100.00	40.36

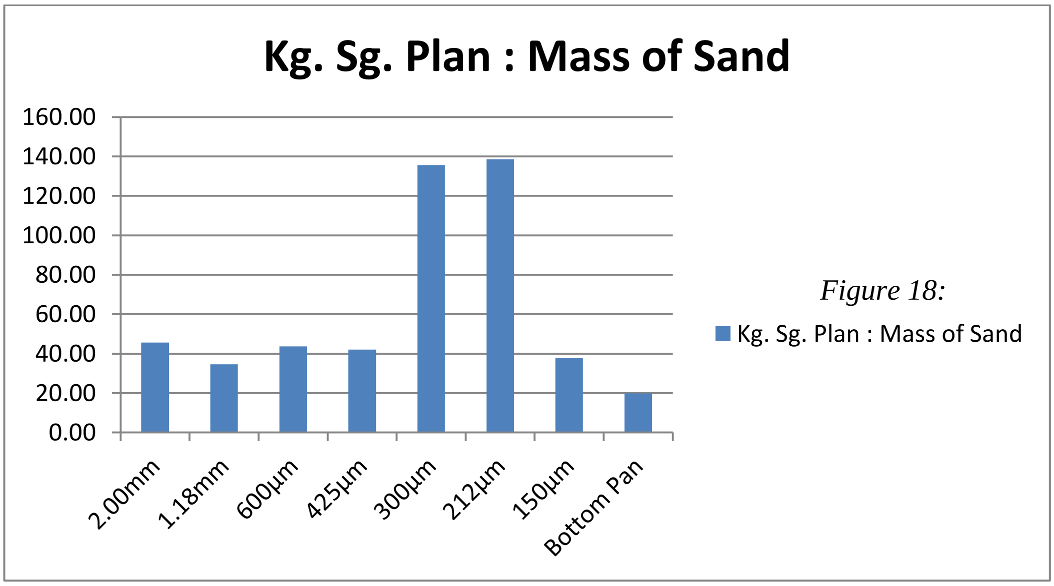


Figure 18:

4.6.4 Kidurong

Sieve Size	Mass Sieve with Sand	Mass Empty Sieve	Mass of Sand	Cumulative Mass of Sand	Mass Percentage	Cumulative Mass Passing each Sieve
µm/mm	gm	gm	gm	gm	%	%
2.00mm	541.50	469.10	72.40	72.40	13.71	91.33
1.18mm	468.03	435.81	32.22	104.62	19.81	87.47
600µm	551.25	403.28	147.97	252.59	47.83	69.74
425µm	531.75	379.12	152.63	405.22	76.74	51.45
300µm	425.59	371.26	54.33	459.55	87.03	44.94
212µm	360.75	344.97	15.78	475.33	90.02	43.05
150µm	379.33	333.52	45.81	521.14	98.69	37.56
Bottom Pan	400.54	393.63	6.91	528.05	100.00	36.73

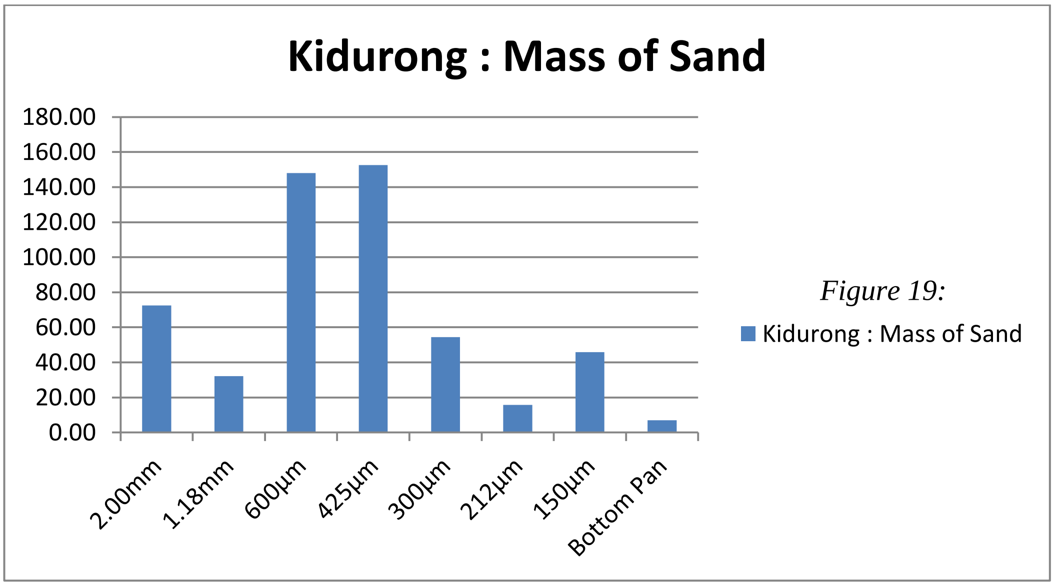


Figure 19:

4.7: GRAIN SIZE ANALYSIS: Histogram Data

4.7.1 Sungai Mas

a. Mode = 425 µm
b. Median = 425 µm
c. Mean= 425 µm
d. Poor Sorting

4.7.2 Samling Estate

a. Mode = 212 µm
b. Median = 212 µm
c. Mean= 150 µm
d. Good Sorting

4.7.3 Kg. Sg. Plan

a. Mode = 212 µm
b. Median = 300 µm
c. Mean= 300 µm
d. Fair Sorting

4.7.4 Kidurong

a. Mode = 425 µm
b. Median = 600 µm
c. Mean= 425 µm
d. Very Poor Sorting

These results are solely based on histogram data; another 2 results will be assessed next.

4.8: CUMULATIVE DISTRIBUTION PLOT ANALYSIS

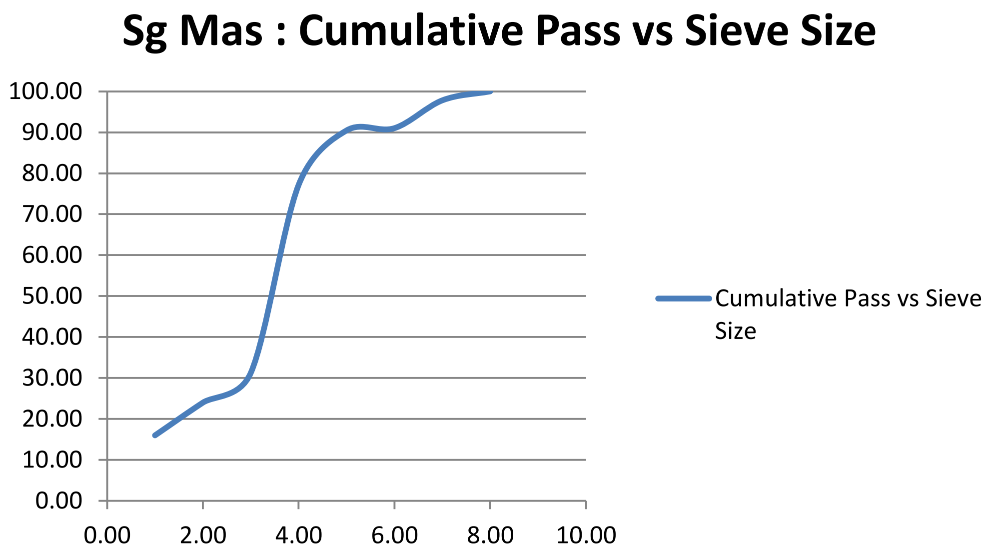


Figure 20 :Particle Size Analysis of Sg Mas outcrop .

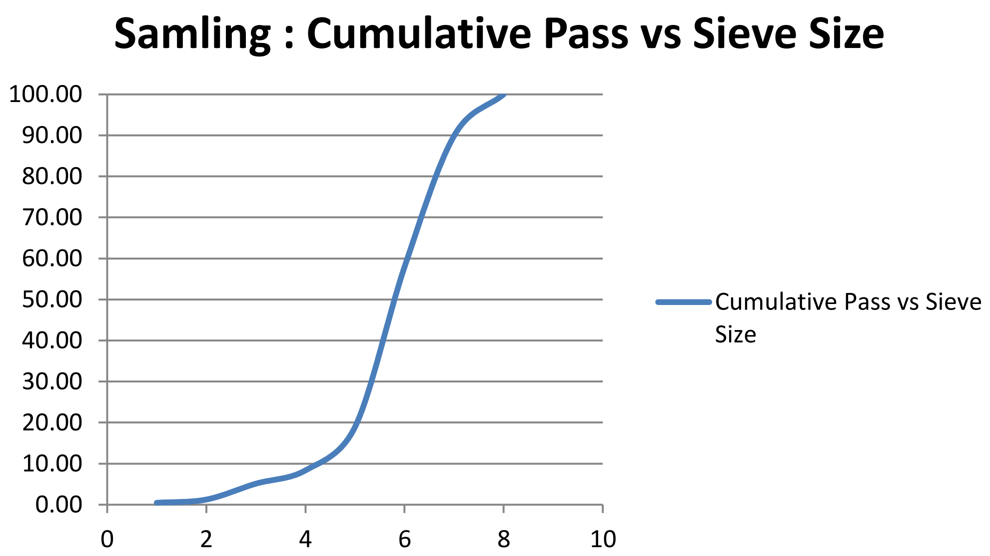


Figure 21 :Particle Size Analysis of Samling outcrop .

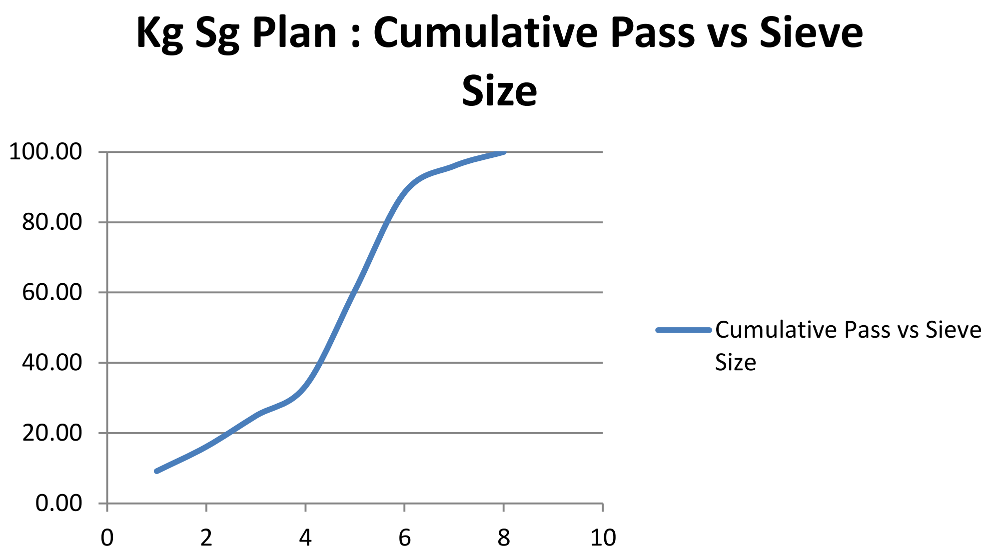


Figure 22 :Particle Size Analysis of Kg Sg Plan outcrop .

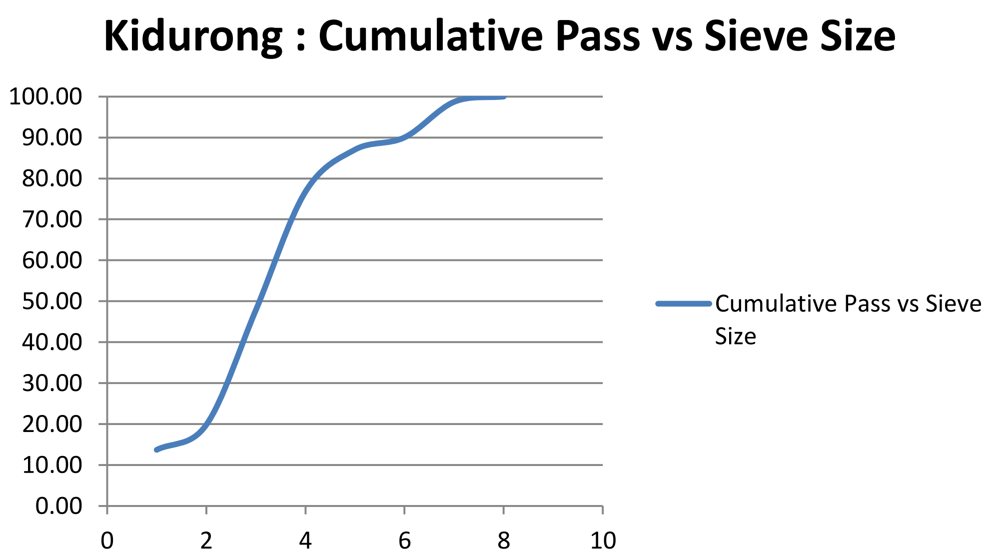


Figure 23 :Particle Size Analysis of Kidurong outcrop .

These results showed the extent of grain size distribution deviation. Good sorting should translate to equally spaced range between sizes showing one population as well as having a tail / head conclusively spaced the smallest. This sorting can be seen for Samling outcrop. As for Kg Sg Plan, the population is not normally distributed with significant increase in certain sizes without any gradual change. Finally for Sg Mas and Kg Sg Plan samples, they possess dual population sizes evidently shown by 2 peaks. This shows that it has poor sorting and can be categorized as having a bimodal distribution.

4.9: LOGARITHMIC PLOT

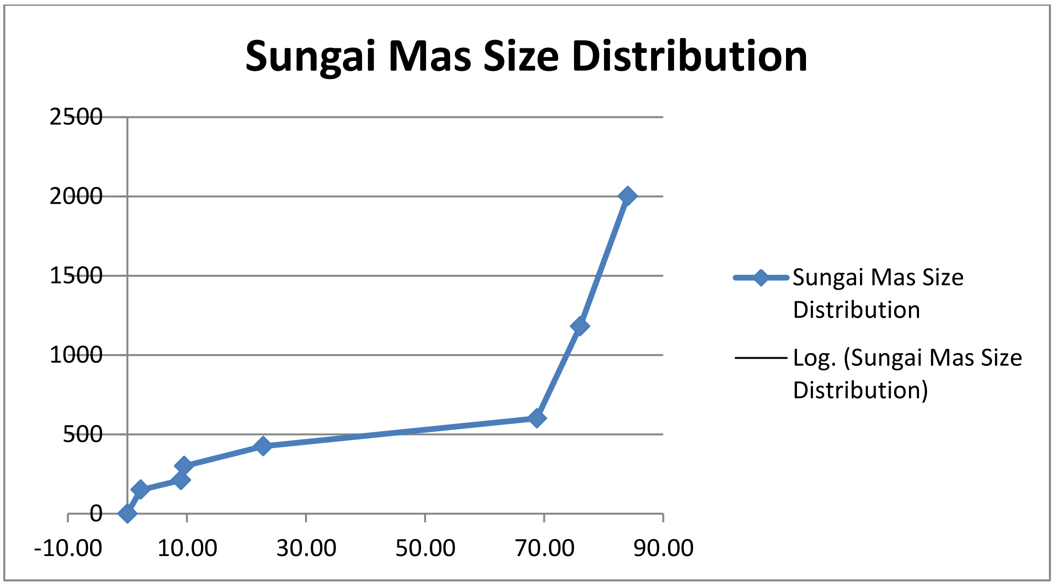


Figure 24 : Logarithmic Plot Analysis of Sg Mas outcrop .

D_{10}=300 µm

D_{30}=500 µm

D_{60}=580 µm

Therefore it is Fine Sand with poor sorting

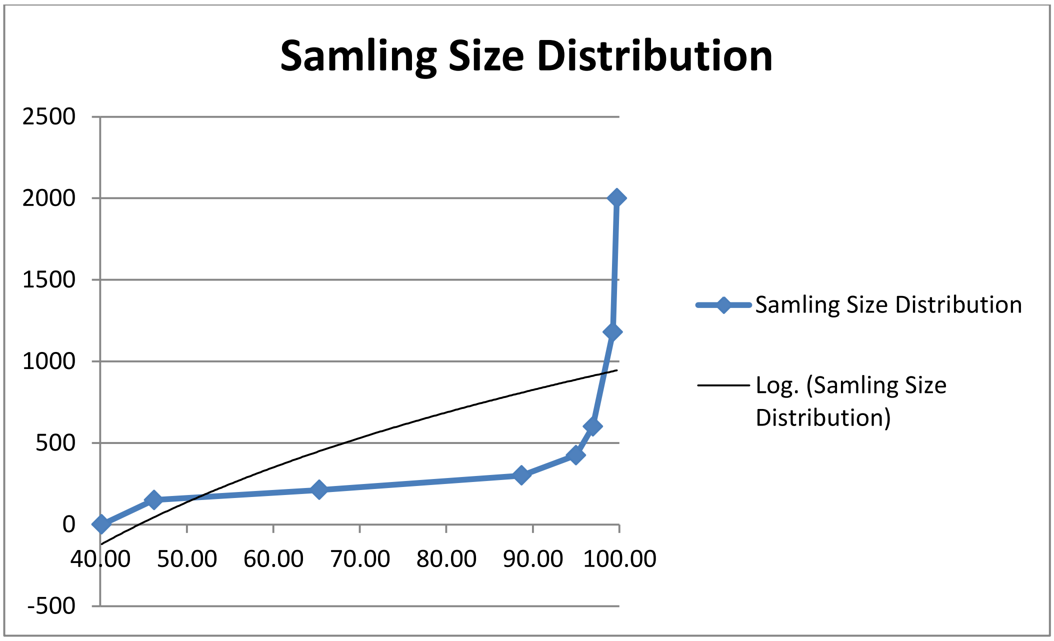


Figure 25 : Logarithmic Plot Analysis of Samling outcrop

D_{10}=0 µm

D_{30}=0 µm

D_{60}=120 µm

Therefore it is Very Fine Sand with Good sorting

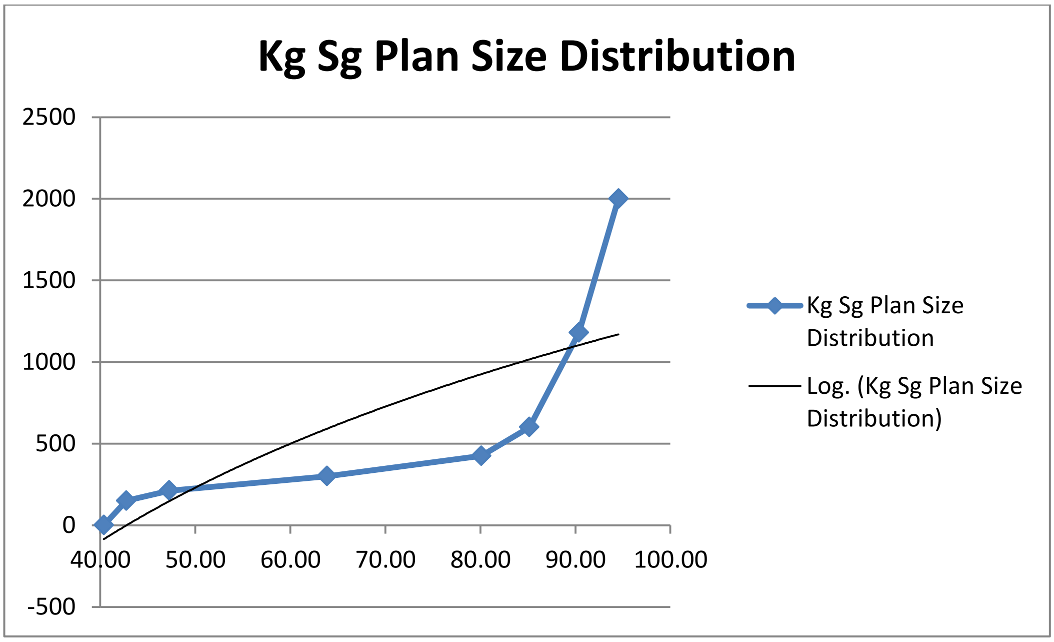


Figure 26 : Logarithmic Plot Analysis of Kg Sg Plan outcrop .

D_{10}=0 µm

D_{30}=0 µm

D_{60}=280 µm

Therefore it is Very Fine Sand with Good sorting

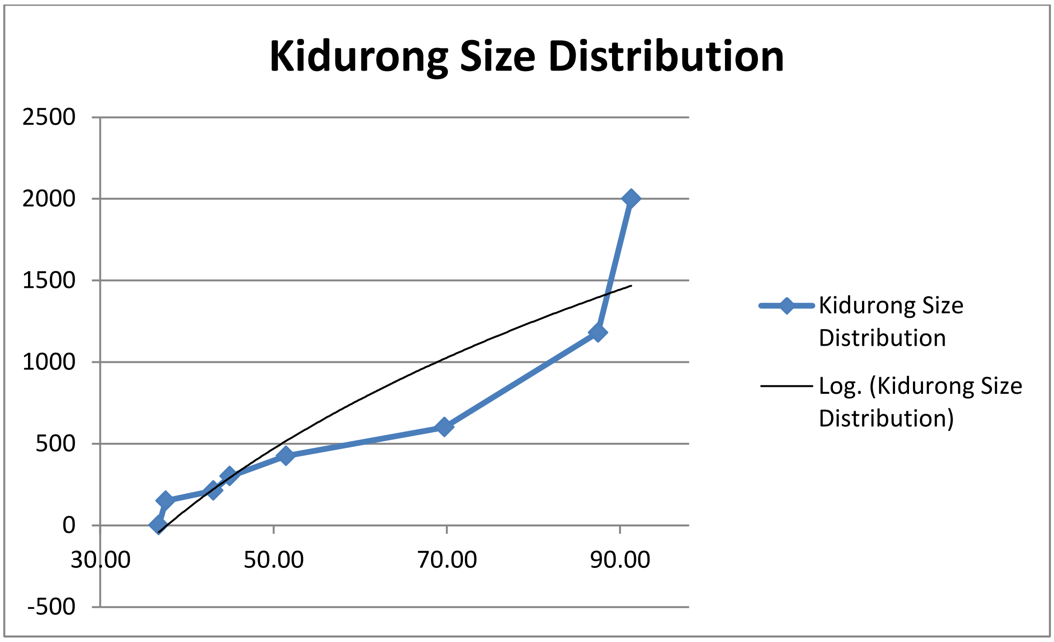


Figure 27 : Logarithmic Plot Analysis of Kidurong outcrop .

D_{10}=0 µm

D_{30}=0 µm

D_{60}=560 µm

Therefore it is Very Fine Sand with Poor sorting

CHAPTER 5

5.1: CONCLUSION

To conclude, the sandstone from Samling holds very good reservoir quality as well as having characteristics of good flow capacity due to fine size sand and good sorting. Apart from that, shale beds as well as coal bed proved the significance of the formation to form fossil fuel. As for Kg. Sg. Plan which sandstone layers have mud-clast, its potential is hampered by the heterogeneities.

Besides this, careful observation and identification of the sandstone features at the field with guidance from my Supervisor as well as my colleague has enhanced my identification skills. On the other hand, laboratory works improve the understanding of the significant parameters such as grain sorting and thickness to the preliminary in-field results. Moreover, petrography parameters will provide the rock's reservoir qualities significant in petroleum engineering field. Finally, establishing relations between the sedimentology qualities and petrography properties will further boost my capacity as a Petroleum Engineering undergraduate student as well as equipping me with the added value of Geoscience knowledge when I join the oil & gas industry upon graduation.

It is my hope that this report will be beneficial not only for me and my research project members, but also towards the geology society in general.

5.2: RECOMMENDATION

The reliability of this research lies heavily upon trained, highly skilled and experienced professionals. Due to the simple methodology of this research, there is not much recommendation to be suggested. My Supervisor Associate Professor Dr. Abdul Hadi Abd Rahman is already the leading expert in this field of study and he has been guiding me and my colleague closely. The only recommendation may be wider sample size should be brought for lesser outcrop location.

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Supervisor : Assoc. Prof. Dr. Abdul Hadi Abd Rahman

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