RECOGNITION OF SEA-LEVEL FLUCTUATIONS IN SILURIAN TO PERMIAN DEPOSITS, PERLIS, MALAYSIA

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by

NURUL SYAZWIN BINTI ZAMRI

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LIST OF SYMBOLS

Di	Actual depth of the ith cycle top
cm	Centimetre
N	Cycle number in the interval
D_O	Depth at the top of cycle number zero
⥮	Fault line
ft	Feet
>	Greater than
<	Less than
m	Metre
µm	Micrometre
mm	Millimetre
%	Percentage
ϕ	Phi
±	Plus-minus sign
T	Total thickness of the interval

LIST OF ABBREVIATIONS

CDMT	Cumulative deviation from the mean cycle thickness
E	Easting
Fm.	Formation
FSST	Falling stage systems tract
GPS	Global Positioning System
HCS	Hummocky cross-stratified
HST	High-stand system tract
JMG	Jabatan Mineralogi dan Geosains
Ky	thousand years/kilo year
LST	Low-stand system tract
Ma	Mega-annum
MTWG	Malaysian-Thailand Working Group
N	Northing
RST	Regressive system tract
Sp.	species
TST	Transgressive system tract
U/C	Unconformity

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PENGIKTIRAFAN PERUBAHAN PARAS AIR LAUT PADA ZAMAN *SILURIAN* HINGGA *PERMIAN* DI PERLIS, MALAYSIA

ABSTRAK

Batuan sedimen kuno dari singkapan lapangan memberikan informasi tentang ciri-ciri sedimen, dan penakrifan sekitaran pengendapan. Kajian ini juga mengiktiraf perubahan paras permukaan air laut pada masa lalu dari batuan sedimen yang tersingkap di negeri Perlis. Dua lokaliti telah dipilih iaitu singkapan di Guar Sanai, Kampung Guar Jentik, dan Bukit Tungku Lembu, Beseri. Pengumpulan data kajian telah dilakukan pada 10hb November 2018. Berdasarkan hasil yang diperolehi daripada analisis cerapan log, analisis fasies pengendapan, dan plot *Fischer*, fasies pengendapan, penentuan sekitaran pengendapan serta perubahan paras air laut dapat dikenalpasti. Hasil daripada kajian tersebut, enam fasies telah dikenalpasti di Formasi Kubang Pasu di singkapan Guar Sanai iaitu selang lapis batu kapur dan batu lumpur hitam, batu syal hitam, selang lapis batu lumpur hitam dan rijang, batu lumpur, batu pasir dan diamiktit; serta jenis litologi menunjukkan pengendapan di antara sekitaran laut dalam ke permukaan darat dengan endapan laut glasier. Selain itu, Formasi Kubang Pasu di singkapan Bukit Tungku Lembu terdiri daripada batu arang, batu syal berlodak, batu syal, batu pasir dan selang seli batu pasir dan batu syal berlodak; yang mana ia merupakan sekitaran pengendapan deposit pantai, yang dipengaruhi oleh ombak dan badai di sekitaran lautan cetek hingga lingkungan pengendapan sungai lama. Seterusnya, batuan formasi Chuping pula terendap di sekitaran laut cetek yang terbatas dan dibahagikan kepada tiga fasies pengendapan iaitu batu kapur breksia, batu dolomit dan batu kapur. Dari analisis plot Fischer, terdapat pengulangan pola jujukan batuan menunjukkan berlakunya aktiviti regressi dan transgressi (perubahan paras air laut). Hasilnya, pengendapan sedimen karbonat dan silikiklastik dari Formasi

Mempelam hingga Formasi Chuping mencangkumi ‘third-order’ urutan siklik. Plot ini bersesuaian dan berkolerasi dengan baik terhadap perubahan permukaan laut global pada Paleozoik Akhir. Tuntasnya, kitaran perubahan paras air laut di singkapan kajian telah menunjukkan fasa regresi dan transgressi yang seiring dengan peristiwa paras laut di rantau dunia.

RECOGNITION OF SEA-LEVEL FLUCTUATIONS IN SILURIAN TO PERMIAN DEPOSITS, PERLIS, MALAYSIA

ABSTRACT

The ancient sedimentary rock from the field outcrop gives information on sedimentary features and enhances the depositional environment history. This research incorporated the information on the past sea-level fluctuations of sedimentary rock succession of Perlis area, particularly in Guar Sanai, Kampung Guar Jentik, and Bukit Tungku Lembu, Beseri area, to verify the events imprinted in the rock record. The data survey was carried out on 10th November 2018 during the mid-semester break. Therefore, this study overview was carried out to analyse the sedimentary facies and reconstruction of the paleo-environment history model for this rock profile via sedimentology logging, facies analysis study, and Fischer plotting analysis. Sedimentological and sequence stratigraphic evidence indicates that the Bukit Tungku Lembu outcrop represents a deposit of coastal, wave, and storm-influenced shoreface shelf system that reflects a shallow marine near fluvial paleo-depositional environment, and the Chuping Formation represents a restricted shallow marine environment. In contrast, the Guar Sanai outcrop represents a deeper marine to shoreface environment with glacial marine deposits. Six sedimentary facies have been recognised in Guar Sanai are which are; (F1) limestone interbedded with black mudstone, (F2) black shale, (F3) black mudstone interbedded with chert, (F4) mudstone, (F5) sandstone, and (F6) diamictite while five sedimentary facies in Bukit Tungku Lembu area which are; (F1) coal, (F2) silty shale, (F3) shale, (F4) sandstone, and (F5) interbedded of sandstone with silty shale and, three sedimentary facies of Chuping Formation which are; (F1) brecciated limestone, (F2) dolomite, and (F3) limestone. The complete sedimentology sequence of Guar Sanai and Bukit Tungku Lembu rock succession is made up of several facies cycles in which the result shows Fischer's transgressive-regressive plots. 3rd-order cyclic and carbonate and siliciclastic sequences in the late Silurian Mempelam Limestone to Early Permian Chuping Formation are identified. The plot matches very well with the Late Paleozoic sea-level changes globally. The results show that the cycles have a synchronous occurrence of falling and rising events in different world regions from past studies.

CHAPTER 1

INTRODUCTION

1.1 Background

Jones (1981) and Gobbett (1973) elucidated the Paleozoic to Mesozoic sedimentary successions in the north-western part of Peninsular Malaysia. It exhibits an in-depth study on the geological work sequence of Upper Cambrian to Holocene. These rock stratigraphies are grouped into, in ascending manner of the oldest to youngest, the Machinchang Formation, Setul Formation, Singa Formation, Chuping Formation, Bukit Arang Coal Bed, Granite, and Alluvium. Foo (1983) quoted that these rocks are comprised of clastics and carbonates sedimentary rock. Its depositional environment is primarily in shelf sediments of shallow marine settings (Foo, 1983).

The underlying focus of this study presents sedimentological observations based on a macroscopic approach to the stratigraphic sedimentary sequence. Incorporated herein are observations, descriptions, and interpretations of 5 measured logged sections through the sedimentary formations outcrop in the Western Belt of North-western Domain Peninsular Malaysia of our studied localities;- Guar Sanai, Kampung Guar Jentik, and Bukit Tungku Lembu, Beseri. The results have been used for facies analysis and paleoenvironmental reconstruction.

In addition to that, the Fischer plot is implemented in this study to portray the sea-level correlation in cyclic sequences of varying thicknesses. These cycles illustrate the relationship between the third-order system tracts (comprising high-stand, low-stand, and quartz-sandy cycle positions) and the correlation between stratigraphic sections as the Fischer plotting are graphically time-coordinated (Read & Goldhammer, 1988).

This study focused on several outcrops in the Northwest of Peninsular Malaysia, Perlis. Jones in 1981 reported that Perlis sedimentary sequence typically begins to young eastward from the Setul Boundary Range. Generally, the structural setting of the area is affected by fold-thrust belt tectonic events initiated during the Late Triassic, represented by the collision between the Sibumasu and East Malaya/Indochina blocks (Metcalfe, 2011). The study was carried out on two localities in the vicinity of Guar Sanai, Kampung Guar Jentik and Bukit Tungku Lembu, Beseri (Figure 1.1). Therefore, five measured sections of the sedimentology log were conducted to determine the sedimentary sequences which occasionally decipher the depositional environment. Plus, the cycle stacking patterns and the lithology correlatability of Fischer plots are used to define the sea-level fluctuation of the Silurian to Permian succession exposed in Perlis.

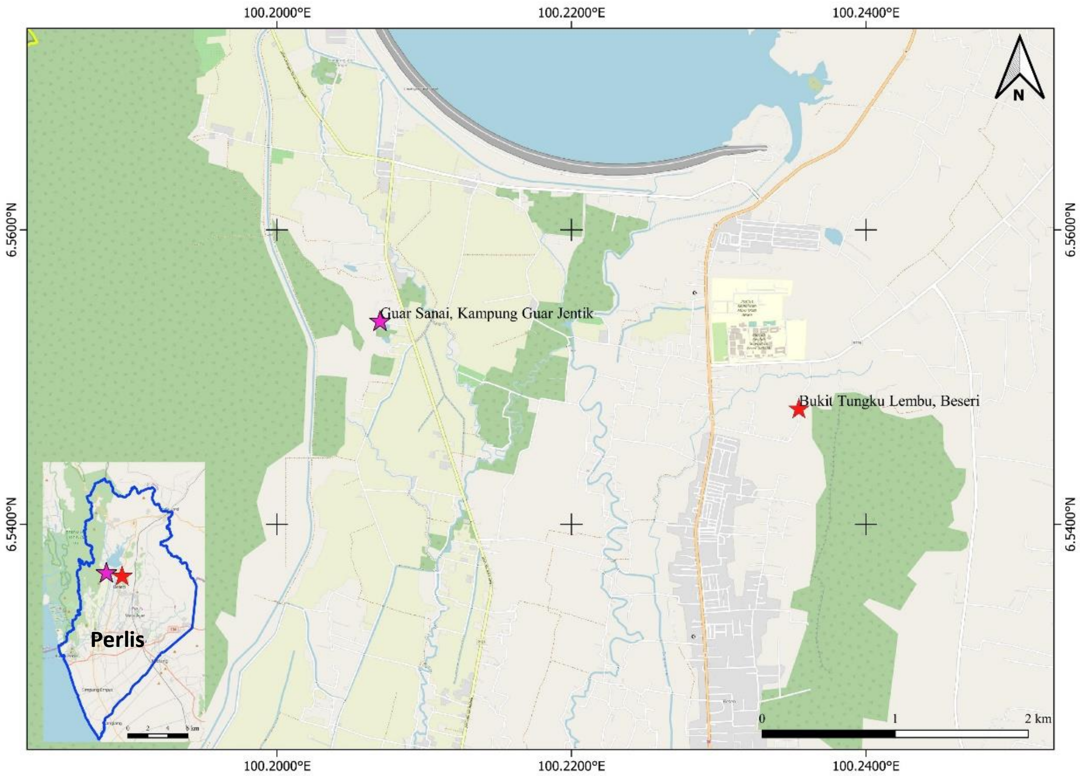

Figure 1.1: Topography map of Perlis, Malaysia showing the location of the study area.

1.2 Problem Statements

Sedimentology studies the rock layers of sand, mud, clay, and silt and the processes involved to understand the origins of the ancient sedimentary rocks. The previous sedimentology works had been carried out by many researchers such as geologists of Minerals and Geoscience Department Malaysia (previously known as Geological Survey Department) in the late 1950s and early 1960s (Gobbet, 1973; Jones, 1981; Hassan and Lee, 2005. Their findings have provided valuable information on comprehensive Paleozoic sedimentary formations of the north-western part of Peninsular Malaysia, ranging from Upper Cambrian to Holocene. In addition, their studies are used for a better understanding of the geology and stratigraphy of the area studied.

The Fischer plot uses the stacked section of the stratigraphic record to extrapolate sea-level change. These plots simply depict changes in accommodation or the amount of space available for sediments deposition throughout time. As there is no information on sea-level history based on stratigraphy studies from the previous researcher, Fischer plots will be imposed to test our hypotheses; is the sea-level constructed from the stratigraphy sequences (sedimentology logging)? Therefore, the results can ascertain and identify the third-order sequence events from the accommodation (Fischer) plots of the cyclic succession.

This research reviews Perlis's rock formation's sedimentological variation (depositional elements and depositional environment) to construct the sea-level curves and correlate with the major eustatic sea-level history during the Paleozoic time scale because there is no information on sea-level history based on stratigraphy studies from the previous researcher.

Hence, this study will emphasise the sedimentary facies of formation to distinguish its depositional environment history by utilizing the sedimentology logging to compare sedimentary outcrop for numerous and diversified applications.

1.3 Research Objectives

The main objectives of the study are:

1. To identify the sedimentary facies associations of formations in Perlis
2. To construct a comprehensible depositional environment model of the facies, based on the identified facies assemblages
3. To construct and correlate the Silurian-Permian sea-level fluctuations to Paleozoic major eustatic sea-level history

1.4 Scope of the Study

Paleozoic sedimentary rocks are present throughout the north-western part of Peninsular Malaysia. This study covers the Late Silurian (Upper Setul Limestone/Mempelam Limestone) to Early Permian (Chuping Formation) portion of strata. The outcrops are at Bukit Tungku Lembu and Guar Sanai in the state of Perlis. The interpretation of the main formation built up in the survey area is based on sedimentological logging. From sedimentology logging, we can observe the interbedded facies of some cycle patterns that usually form patterns of coarsening upward and fining upward. Depositional environments are interpreted for each of the lithologic units. The cycle thickness for Fischer plot analysis will be determined based on the sedimentology log and facies association.

1.5 Significance of the Study

The significance of the research study is to produce an updated version of sedimentary facies of formation in north-western Peninsular Malaysia. A comprehensive geological map is vital for researchers to understand the research area.

Cook (2015) stated that facies analysis interprets the strata in terms of depositional environments. Facies analysis involves describing and classifying a sedimentation unit and interpreting depositional process and environment settings (Lindholm, 1987). The sedimentology logging method provides information on the lithology and the types of facies found in the area. Hence, the results can be used to ascertain the environments of deposition in the study area.

Previous studies have not explained the sea-level fluctuation activities in Northwestern Peninsular Malaysia. Thus, the signature of the study is to publish the sea-level history of Silurian to Permian in north-western Peninsular Malaysia, Perlis state particularly. A precise and accurate sea-level model is essential to verify the events imprinted in the rock record. Furthermore, suppose those correlations must be sufficiently accurate to demonstrate the synchronous occurrence of rising and falling events in different regions of the world. Hence, it is now possible to further interpret the Silurian-Permian sea-level activities through sedimentology logging and Fischer plotting.

1.6 Thesis Organization

This section describes the layout of the thesis as follows. Generally, the thesis comprises five chapters.

Chapter 1 portrays the overview of the research, problem statement, objectives, scope of the study, and significance of the research study. This chapter gives background and highlights the problem by describing the problems conceptually or theoretically. Moreover, it sets forth the scope and deliverables of the study.

The literature review is mainly discussed in Chapter 2. The literature review guides the author to have a clearer understanding of the academic research. Results and findings from previous researchers or geologists related to the study area and their methods are discussed in detail. The sedimentary rock is categorized into Folk Classification (1959, 1962) and Dunham Classification (1962). These sedimentary classifications divide sedimentary formations subject to matrix content. The study areas and geological background are stated accordingly. Other researchers conducted several studies using sedimentological logging and Fischer plotting in site investigation fields, as our choice of methodology is also considered for this project's literature review.

Chapter 3 is the methodology used to analyse the physical properties of sedimentary outcrop by field data observation, sample collection, and the integration of geophysical and geological approaches. The basic framework and principles of the designed methodology are shown in this chapter. Plus, the flowchart of the whole research is visualized to facilitate this research.

The results and data of these investigations are further explained in Chapter 4. The overall discussion is also presented in Chapter 4, which is based on our analysis and observation. The strata of the composite measured section are established and interpreted in their facies associations and depositional environments. The sea-level interpretation is presented in graph form to analyse the present stratigraphic sequence to supply sediment and space available for the accumulation of sediment.

Finally, Chapter 5 is the recapitulation of the study's findings and any further recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

First and foremost, the fundamental concept of sedimentary rock includes its definition and classification presented in this chapter to understand the sedimentology study better. Sedimentology studies the rock layers of sand, mud, clay, silt and the processes involved in understanding the origins of the ancient sedimentary rocks. Furthermore, the study area's geological background and facies analysis are also accommodated in this chapter by research writings of previous studies. Bukit Tungku Lembu and Guar Sanai area in Perlis are chosen as our studied section. North-western Peninsular Malaysia possesses a remarkably long history of published geology research and Paleozoic study, dating from 1966.

A few case studies are to be discussed in this project: sedimentary formations and the sedimentological logging approach. The depositional environments by the rock facies will also be addressed. The descriptions of the depositional environment may tell us something that has occurred in the past at a particular time but is not reflected on the current modern Earth. With that, the collective sedimentological data will validate those proposed hypotheses.

Along with this, the Fischer plot method is also used to reveal the sea-level history of the sedimentary formation in north-western Peninsular Malaysia of Silurian to Permian age. A precise and accurate sea-level model is essential to verify the events imprinted in the rock record. Supposedly, correlations must be sufficiently accurate to demonstrate the synchronous occurrence of rising and falling events in different world regions.

2.2 Sedimentary Rocks

The sedimentary rock makes up three-quarters of the world's land area and just a quarter of the igneous and metamorphic rocks (Clarke, 1924). Sedimentary rocks are derived from weathering, erosion, deposition or precipitation, and lithification in sedimentary basins of older pre-existing rocks. So basically, fragments and remains of rocks (or clastic rocks) or organic materials (or bioclast), or chemical precipitation (or chemical rock) form the sedimentary rocks. The great bulk of sedimentary rocks originated as deposits on the seafloor, but some were laid down in freshwater and a few on the land's surface. As a result, sedimentary rocks invariably possess a layered structure or stratification.

The sedimentary rock can be categorized into two types of grain size: carbonate rock and clastic rock. Clastic sedimentary rocks can be classified via Wentworth grade scale, while carbonate rocks can be graded and categorised by Folk Classification (1959), Dunham classification (1962), and Embry and Klovan classification (1971).

2.2.1 Clastic Rocks

The main component to be considered in naming clastic rocks is the composition and size of the particles, the shapes and degree of sorting, and their type of cement material. Figure 2.1 presented the Wentworth Classification that is the most widely used scale of particle sizes.

Roundness and sphericity are the two main shape characters. If all the particle sizes are about the same size, they are well-sorted grain, whereas a diverse range of sizes is a poorly sorted grain. The most ordinary cementing materials are silica and calcite, referred to as siliceous and calcareous. Other types of cement are iron oxides or hydroxides (ferruginous) and phosphates (phosphatic), but they are rare.

A study on clastic sedimentary rocks classification by Malaza et al. (2016) had used two complementary techniques, petrography and geochemical methods, to construct the sedimentary origin in the north-eastern part of South Africa in the Tshipise-Pafuri basin. The petrographic analysis of a clastic rock or rock fragment shows detrital-rich constituents, namely feldspar, quartz and, lithic. Also, geochemistry analysis disclosed the content of clastic rocks, i.e., matrix, heavy minerals, major detrital phases, and diagenetic or metamorphic minerals (Malaza et al., 2016).

2.2.1 (a) Wentworth Classification

Geologists often use the Udden-Wentworth grade scale (1922) or now commonly called Wentworth Classification, to define the texture of clastic fragments or particle sizes. It is presented in Figure 2.1 below. In 1898, Udden had first introduced the grain size classification scheme in numerical grade scale. He proposed using 1 millimetre as the starting point, increment multiples of 2 for courser grain class, and increment multiples of ½ for finer ones (Blair & McPherson, 1999). According to Hobson (1979), Wentworth (1922) adopted and enhanced the Udden's grain-size classification by adding descriptive terms for the grades such as sand (ranging from very coarse, coarse, medium, fine, and very fine sand) and silt (ranging from coarse, medium, fine, and very fine silt). Thus, the size class used is clay particle, silt, sand, and gravel (boulder, cobble, pebble, granule).

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	
	64		-6.0	Pebble	
	4		-2.0	Granule	
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	
1/2	0.50	500	1.0	Medium sand	
1/4	0.25	250	2.0	Fine sand	
1/8	0.125	125	3.0	Very fine sand	
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	
1/64	0.0156	15.6	6.0	Fine silt	
1/128	0.0078	7.8	7.0	Very fine silt	
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

Figure 2.1: Grain size classification for clastic sedimentary rock (Wentworth, 1922).

The gravel class is used for a material consists of small pebbles, and granule and gravel can be combined to be boulder gravel, cobble gravel, pebble gravel, and granule gravel. Boulder class is used for smoothed and rounded masses of rock larger than a cobble. Cobble or cobblestone is referred to rounded stone more diminutive than a boulder and larger than a pebble. Pebble class is used for rounded and transported rock fragments smaller than cobbles. The term granule is spherical rock fragments bigger than very coarse sand grains but smaller than pebbles. The term sand is commonly used for mineral grains <1 millimetre or 2 millimetre larger than silt. Sandstone can be graded by dividing into very coarse sandstones, coarse sandstones, medium sandstone, fine sandstones, and very fine sandstones. Smaller individual particles that are very tiny, like sand grains but bigger than clay particles, are referred to as silt particles. Meanwhile, clay particles are used for the particle that is finer than silt. Clay is the finest clastic sediment. Shale is referred to as the shelly and fissile structure of the rock compared to its grain size.

2.2.2 Carbonate Rocks

Carbonate rocks represent one of the significant sedimentary materials and are distributed abundantly on the surface of the Earth. It is not only possessing natural resources but also economically significant. It contains the history of the Earth in interpreting ancient depositional environments.

Sharma et al. (2012) stated that sedimentary carbonate rocks consist primarily of carbonate minerals. They are referred to as carbonate rocks because they contain significant chemical contents of carbonate, CO_3. Plus, carbonate rocks are also the most abundant non-terrigenous sedimentary rock (Sharma et al., 2012). Carbonate rock contains greater than 50 percent carbonate materials ($CaCO_3$). There are two main kinds of carbonate rocks which are limestones and dolostones. Carbonate rock has two major types: limestone consisting of aragonite or calcite, and dolostone consisting of the dolomite mineral (Scoffin, 1987). Most of the carbonate rocks are from the accumulation of bioclast, which is from the calcareous organism. Thus, carbonate rock originates in favouring biological activity such as shallow, clear, and warm sea (Sharma et al., 2012).

As Scholle and Almer-Scholle (2003) stated, hydrocarbons may be discovered as interstitial material in carbonate rocks or fluid inclusions in carbonate cement. Thus, evidence of hydrocarbon entry into the ancient rocks and curved meniscus cement includes residues and inclusion and preserving unstable carbonate phases, i.e., aragonite.

The classification of carbonate rock is divided into three classes which are Folk Classification (1959), Dunham classification (1962), and Embry and Klovan classification (1971). These classification schemes for carbonate have various properties for classifying carbonate rock, such as colour, grain size, crustal size, composition, texture, and distribution. In addition, these classifications help determine and observe the sample in petrographic analysis.

Folk Classification (1959) was first introduced to incorporate the sedimentary origin, matrix component composition, size of the grain, and depositional environment. It was further expanded in 1962. This classification is best suited to study limestone under petrographic or thin sections.

Dunham (1962) was then proposed an alternative classification scheme. This approach is best when using a hand lens or binocular microscope to describe limestone. In 1979, this scheme was modified by Embry and Klovan. However, Dunham's classification is more favourably applied in the exploration of the oil and gas sector.

Thus, this section describes the carbonate classification as follows.

2.2.2 (a) Folk Classification

Folk describes the significant limestone constituents and the abundance of micritic matrix versus open pore space or sparry calcite cement to fill such pores. Allochems, which include intraclasts, oolites, fossils, and pellets, are also called framework grains. Micrite, which is called sparry calcite, is the fine-grained carbonate cement that is chemically precipitated.

Allochemical rock can be divided into two, which are spar and mic. Spar is made up of transparent coarsely crystalline mosaic calcite crystals in a sparry calcite cement.

At the same time, the mic includes microcrystalline calcite mud, micrite, which is mud supported (Figure 2.2).

Scholle and Ulmer-Scholle (2003) summarised that the rock is an intraclastic carbonate rock if >25% of grains are intraclasts, the rock is an oolitic carbonate limestone if <25% of grains are intraclasts and >25% are ooids, and the rock is a pelletal or biogenic carbonate rock if both intraclasts and ooids are respectively <25% each. Thus, it is highly dependent on the consecutive percentages of those grains that existed.

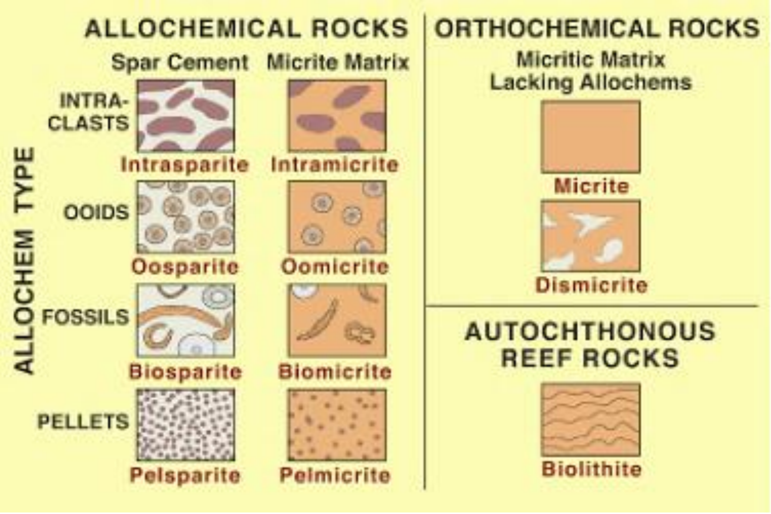

Figure 2.2: Folks Classification (1959) of limestones (Scholle & Ulmer-Scholle, 2003).

Strohmenger and Wirsing (1991) further extend the Folk's classification by adding ocoids and extraclasts into the rock name categories. Suppose the carbonate rocks comprise >20% or >40% of skeletal grains/peloids, the frequency boundaries for grains and the incorporation of all grains in the rock name will also change (Flugel, 2004). In Figure 2.3, Folk further introduced the classification by the textural element that depends on the grain size, micrite matrix and cement, and roundness and sorting (Adams & McKenzie, 1998). There are eight main stages from Figure 2.3 that reflect the deposition of sediments ranging from low energy of micrite matrix to a high-energy of sparite cement.

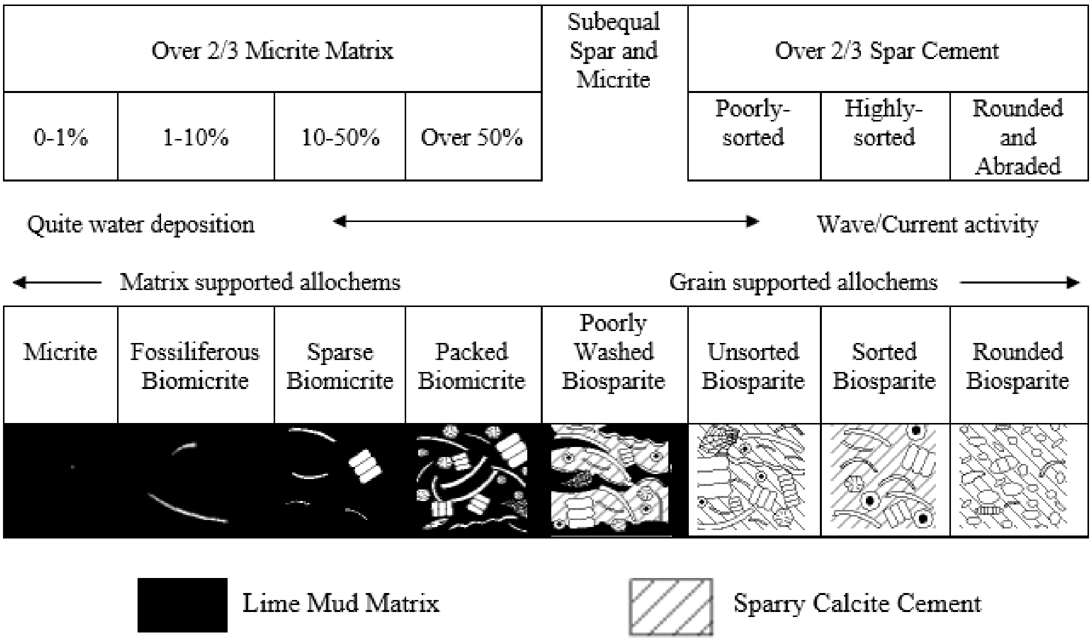

Figure 2.3: Folks Classification (1959) of limestones (Scholle & Ulmer-Scholle, 2003).

2.2.2 (b) Dunham Classification

In 1962, Dunham evolved a new classification aimed at vast application needs, and this classification has been often used nowadays, especially in the oil and gas industry. Dunham's is oriented upon the depositional texture of the limestone rather than the carbonate grains identity, where the original components are not bounded together during deposition (Figure 2.4).

Dunham suggested two rock components for classifying carbonates which are grain-supported and mud-supported. Five of Dunham's major classes are mudstone, wackestone, packstone, grainstone, and boundstone. Mudstone and wackestone are mud-supported, while packstone is grain-supported depending on their lime-mud content. Boundstone is biogenically bound sediment. Mud content is crucial in determining the depositional environment previously (Roehl & Choquette, 1985).

As in the Folk's classification spectrum, the depositional energy of the environment is mainly associated with the deposition textures of carbonate grains.

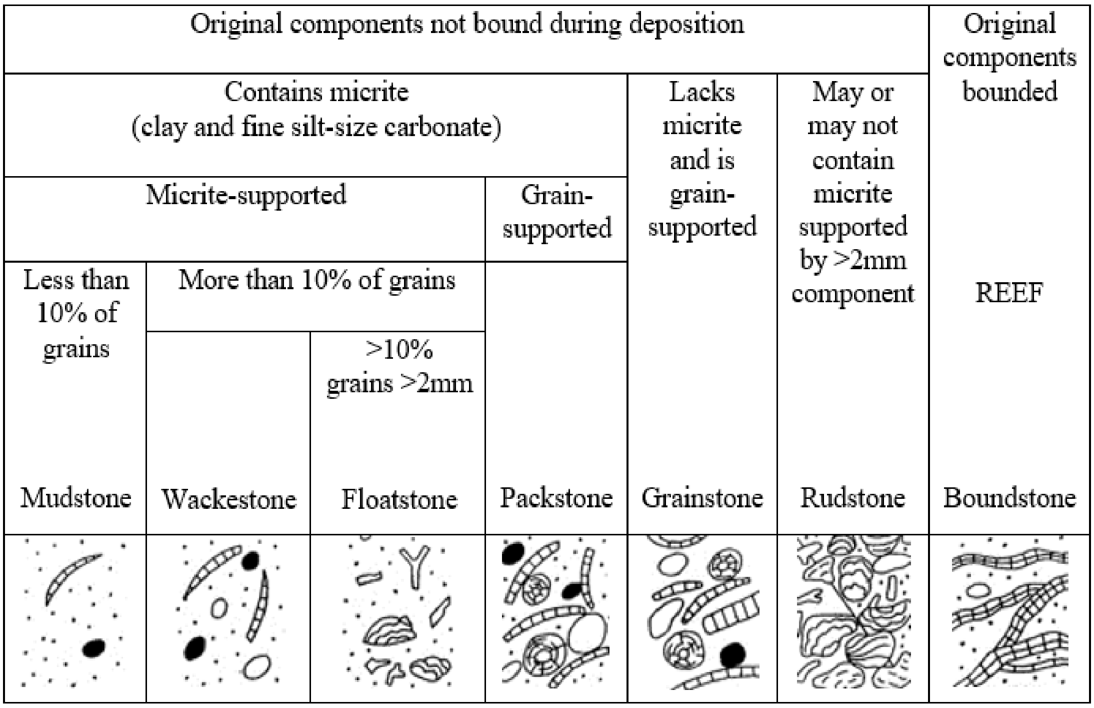

Figure 2.4: Dunham Classification (1962) according to deposition textures of carbonate grains (Saputra, 2016).

2.2.2 (c) Embry and Klovan Classification

The Dunham classification was then revised in 1971 by Embry and Klovan by introducing the coarse-grained carbonates or specifically accommodate the biogenically bound carbonates. From Figure 2.5, this classification shows that it retains Dunham's fundamental terms, grain-support, and mud-support, and introducing the bafflestone, bindstone, and framestone carbonate terms, which referred to reef's organism growth patterns (Ahr, 2008).

Bafflestone is built by organisms that act as baffles with high concentrations of lime mud. The term bindstone is formed by the organisms that encrust and bind, and the framestone is produced by an organism that builds a rigid framework or a girder-like frame arrangement. Boggs and Krumbein (1996) stated that this subdivision of boundstone includes mixing genetic and descriptive parameters in the same classification.

<table>
<tr><td colspan="6">Allochthonous limestone:
Original components not organically bound during deposition</td><td colspan="3">Autochthonous limestone:
Original components organically bound during deposition</td></tr>
<tr><td colspan="4">Less than 10% >2mm components</td><td colspan="2">Greater than 10% >2mm components</td><td rowspan="3">By organisms that act as baffles</td><td rowspan="3">By organisms that encrust and bind</td><td rowspan="3">By organisms that build a rigid framework</td></tr>
<tr><td colspan="3">Contains fine mud
<0.03mm</td><td>No lime
mud</td><td rowspan="3">Matrix supported</td><td rowspan="3">>2mm component supported</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2" rowspan="2">Grain supported</td></tr>
<tr><td>Less than 10% grains >0.03mm to <2mm</td><td>Greater than 10% grains</td><td colspan="3">Boundstone</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Floatstone</td><td>Rudstone</td><td>Bafflestone</td><td>Bindstone</td><td>Framestone</td></tr>
</table>

Figure 2.5: Embry and Klovan Classification (1971) based on carbonate grain size (Boggs & Krumbein, 1996).

2.3 Facies Analysis and Depositional Environment

The set of features involved for this sub-topic are mainly the lithology and sedimentary structures. Sedimentary facies represent the characteristics of a sedimentary unit, including dimensions/geometry, sedimentary structures, lithology, e.g., grain sizes and types, colour, and biogenic content (fossils). When these facies are grouped, they will form the associations of facies. Subsequently, each defined facies association would indicate a particular depositional environment. Therefore, the continuous facies successions composed of repeated-stacked facies associations are then identified based on larger-scale vertical facies trends (Hassan et al., 2014).

For geologists to interpret the depositional environment, one must have extensive knowledge and thorough experience to objectively deduce the paleo-environment history on how the sediment was transported. The depositional environment can be characterized by several processes of physical, biological, and chemical, respectively. These parameters are used to determine the condition of the sediments on how intense these processes had affected the sedimentary settings and how long the duration which such action is continued (Pettijohn, 1957). Hence, the descriptions of the depositional environment may tell us something that has occurred in the past at a specific time but is not reflected on the current modern Earth.

Cook (2015) stated that facies analysis interprets the strata in terms of depositional environments. According to Lindholm (1987), facies analysis describes and characterizes the sedimentation unit and concludes it into a depositional environment. A facies model is an interpretive device erected by geologists to explain the associated facies (Miall, 2013). Several parameters are discussed when discussing facies analysis: geometry, lithology, main fossils, sedimentary structure, and paleocurrents. From the facies descriptions, it can provide us information on the depositional processes and their depositional settings. Geologists study sedimentary rocks to help them grasp past geological history.

Selley (1985) showed that geometry indicates sedimentary facies' overall shape that reflects its pre-depositional topography, geomorphology of the depositional environment, and post-depositional history. Geometry can be relatively determined from the outcrop surface. In contrast, Tucker (2001) focused more on its lithology, which describes the physical characteristics. In terms of sedimentary rock, lithology is considered how the rock is transported on land from which it originated.

Facies that are characterized based on fossil content are called biofacies. They are handy to ascertain the relative ages of rock strata. Geologists use them to assess and compute specific depositional environments and provide some geological proof for organic evolution. For instance, Aung et al. (2013) used fossils as part of a facies analysis of the uppermost part of the "Sanai limestone" by the discovery of Late Devonian (Frasnian) conodonts in Guar Jentik, Perlis.

According to Potter and Pettijohn (1978), the paleo-current study utilizes the sedimentary features to estimate the flow direction in the field. For instance, the river, streams within a basin, oceanic currents, and cross-bedding dip direction. Sedimentary structures are used to recreate the sedimentary process. Integration of paleocurrent map with other lines of facies analysis can make up the environment and paleogeography.

The lithostratigraphy and depositional environment of the transitional zone from the Setul Limestone to the Kubang Pasu Formation studied in Guar Sanai, Kampung Guar Jentik, Beseri, Perlis on the sedimentology and paleontology analysis (Meor & Lee, 2002). A new lithostratigraphic unit has been distinguished; the Jentik Formation consists of six informal units which are namely Unit 1, Unit 2, Unit 3, Unit 4, Unit 5, and Unit 6 (Meor & Lee, 2002). Unit 1 predominantly comprises black shales that are of an early Devonian age-dating faunal assemblage (*Dacryoconarid-Monograptus-Plagiolaria*). Light-coloured, unfossiliferous sandstones and shales are fall in Unit 2. In addition, Unit 3 consists primarily of thick and red sandstone, interbedded with sandstone and occasionally showing graded layer/bed. Unit 4 allocates a dark well-bedded limestone layer having straight coned *nautiloid* fossils. Unit 5 is made up of interbedded layers of cherts and slump structures in beds of black mudstone. Fossil of brachiopod and gastropod is found at the base of the bed unit. Unit 6 comprises primarily brownish to red thickly bedded of mudstone, interbedded with sandstone. *Macrobole*-crinoid fossil assemblage in the thick-redded mudstones resembled the Early Carboniferous dating age. The Jentik Formation is located underlying the

Kubang Pasu Formation. Thus, these features generally suggest that the environments reflect depositional settings within relatively deep water marine environments.

The Unit 3 of the Jentik Formation (Meor & Lee, 2002) or the Rebanggun Beds (Gobbett, 1972) or the Langgun Red Beds (Kobayashi & Hamada, 1973) is exposed in the Hutan Aji District, conformably overlying the light-coloured areno-argillites of Unit 2 (Meor & Lee, 2002) or the Upper Detrital Member (Jones, 1981). The Mid-Paleozoic red beds have indicated that this formation corresponds to the transgressive event documented worldwide, the Hangenberg Event. Hassan and Peng (2004) presented comprehensive sedimentology and paleontology studies to determine the depositional environment of the Late Devonian-Early Carboniferous red beds sequence. The sedimentological logged revealed that the formation is constituted by massive mudstone, thin mudstone to sandstone couplets, and thin tabular sandstone. The rocks of the Jentik Formation in Unit 3 can be divided into eight facies which; massive mudstone facies, thin mudstone and sandstone couplet facies, pebbly sandstone facies, massive sandstone facies, cross-stratified sandstone facies, black mudstone facies, hummocky cross-laminated sandstone facies, and laminated sandstone facies. These findings demonstrate that it was deposited in a marine prodelta to delta front environment with conditions above the storm-wave base of deep water. These data and field observations show that the red beds' sequence can be considered part of the Jentik Formation deltaic marine deposits.

Meor et al. (2013) studied the sedimentology and facies analysis of Perlis's geological rock formations. The uppermost section of Kubang Pasu Formation clastic deposition shifts to Chuping Formation carbonates using the logging method in Bukit Chondong and Bukit Tunku Lembu. For which three facies associations (with eleven facies) have been identified reflecting different depositional settings. The stack facies' patterns show a gradually coarsening upward sequence ranging from the offshore to distal lower shoreface to proximal lower shoreface facies. As a result, a depositional-environmental model is constructed (Figure 2.6), depicting a prograding storm- and wave-influenced coast, attributed to the upward shoaling pattern of the facies association predominance of a storm- and wave-generated facies.

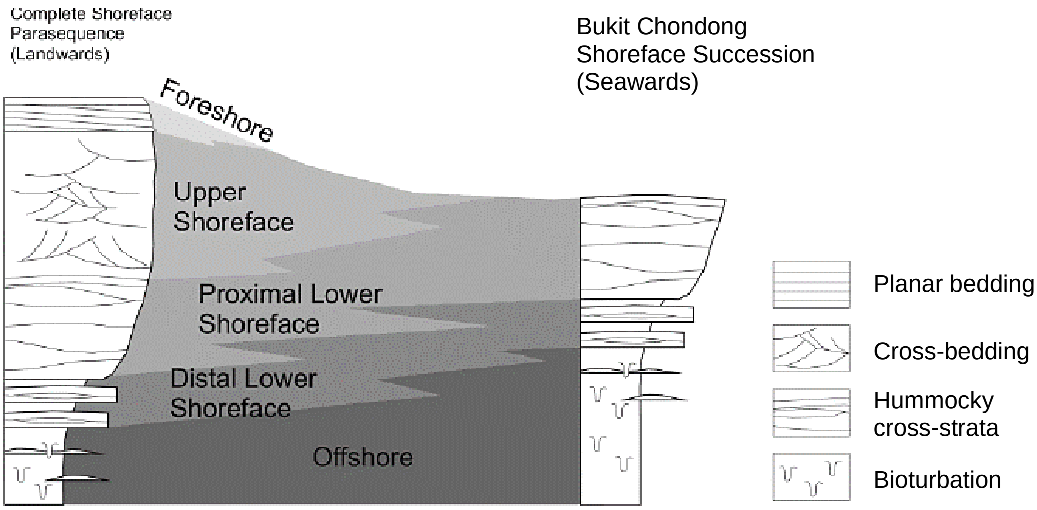

Figure 2.6: Of three facies associated with different depositional settings in the uppermost member of Kubang Pasu Formation (Meor et al., 2013).

The Setul Formation or Setul Limestone with the age of Ordovician to Lower Devonian (Jones, 1981) encompasses limestone exposures in Langkawi's western region and limestone quarry in the northern part of Perlis. Ali and Mohamed (2013) investigated the sedimentological studies and diagenetic process characterization of the Setul Formation in the Kilim area, Langkawi and Kang Giap Quarry, Perlis. According to petrographical studies of thin sections available, seven types of microfacies related to broad environments of shallow to deep marine carbonate ramp have been identified, which are deposited in a tidal flat, lagoon, or protected environment skeletal shoal, and deeper outer ramp. Different diagenetic processes affected this rock formation: cementation, dolomitization, stylolitization, neomorphism, dissolution, compaction, and micritization.

Petrographic analysis is done by Aung et al. (2013) to study geomorphology and mineralogy of Sanai Limestone in Guar Jentik in the Kampung Guar Jentik of Hill B. According to microscopic fossils in the carbonate section, a relatively deep-water marine environment was identified. The sedimentary limestone also has numerous pelagic fossils, including tentaculitids, conodonts, straight-coned nautiloids, ostracods, and trilobites. The simultaneous presence of conodont fossils represents the latest Upper Frasnian age of linguiformis Zone.

Diagenetic history processes of limestone deposits from Bukit Tungku Lembu have been carried out complimented with sedimentological, petrographical, and geochemical analysis (Adenan et al., 2017). Petrographic analysis results indicate that the limestone comprises carbonate microfacies including breccia or also known as intraclastic limestone, dolomites, mudstones, wackestones, packstones, grainstones, and oolitic limestone. The environment of deposition is interpreted as the marine environment, which comprises various diagenetic environments from shallow marine phreatic carbonate, meteoric to deeper burial environments. The dolomitic limestone in Chuping Formation occurs as a replacement process that originates in shallow and late burial diagenetic settings (Adenan et al., 2013).

A chert-bedded sequence situated at the basal bed of Kubang Pasu Formation is minorly dispersed in north-western Peninsular Malaysia (Basir & Zaiton, 2001). A relatively full-covered and well-maintained rock sequence is exhibited at several chert outcrops exposed in Kedah and Perlis. The fossil assemblages of radiolarian chert observed indicate a near the outer shelf of the passive continental margin depositional environment for the late Tournaisian chert bedded of Kubang Pasu Formation. The occurrence of upwelling of dissolved silica and nutrient-rich water mass triggers the high siliceous productivity.

Hassan et al. (2014) assigned the Chepor Member, basal of the Kubang Pasu Formation, into several microfacies to specific depositional environments from an Early Permian age. A grey to red coloured thickly-bedded fossiliferous mudstone with interbedded quartzitic and feldspathic sandstones represents a shallow marine environment. From the facies analysis, the Chepor Members are classified into four facies which; mudstone facies, graded sandstone facies, clean sandstone facies, and diamictite facies. The various facies were deposited with the combination of glacial-derived dropstones and diamictites, shallow marine, shelf facies, and a marine fossil assemblage indicate a glacial marine depositional setting, with the dropstones and diamictites originating as fall out debris from melting icebergs.

2.4 Geological Background of Perlis

Perlis is the smallest state in Malaysia yet, it has numerous unique geological shreds of evidence (Basir, 2010). Arafin and Lee (1989) claimed that Perlis is also a potential source of groundwater due to the presence of karstic limestone. Geologists have drawn a ton of attention (Jones, 1981; Meor & Lee, 2002; and Cocks et al., 2005) to Paleozoic stratigraphy of North-western Peninsular Malaysia because of the interest in its past tectonic evolution as it has been part of the Northwestern Australian Gondwana margin. The Western longitudinal belt of Peninsular Malaysia forms part of the Sibumasu terrane that was rifted from Northwestern Australian Gondwana in the early Permian period (Metcalfe, 1984; 2011).

Jones (1966) had first profound thorough Paleozoic formations in Langkawi Islands of North-western Peninsular Malaysia, the Cambrian Machinchang Formation, the Ordovician to Silurian Setul Formation, the Carbo-Permian Singa Formation (or Kubang Pasu Formation), and the Chuping Formation. Jones (1981) then characterized the sedimentary successions of North-western Peninsular Malaysia into seven major formations: Machinchang Formation, Setul Formation, Mahang Formation, Kubang Pasu Formation, Chuping Formation, Bukit Arang Layer, and alluvium. The North-western zone here covers the Langkawi Islands, Perlis, and Mainland Kedah.

On the other hand, Lee (2009) and Meor et al. (2013) had also introduced a revised Paleozoic rock of Perlis into several separated subunits, from oldest to youngest; Timah Tasoh Formation, Sanai Limestone, Telaga Jatoh Formation, Kubang Pasu Formation, and Chuping Limestone (Figure 2.7). Meor and Lee (2005) discovered a new stratigraphic formation of the Early Carboniferous-Devonian Jentik Formation representing the transitional boundary between the underlying Ordovician-Silurian Setul Formation and the overlying Carboniferous Kubang Pasu. It was once considered as part of the Kubang Pasu Formation before the discovery.

Due to various researchers' different opinions, the author uses the Paleozoic succession documented by Jones (1981) throughout this research. The idea is being supported by Arafin and Lee (1985), which stratigraphic units from Jones (1981) are well-portrayed to Perlis's geology that majorly comprises (of youngest to oldest formation): Chuping Formation, Kubang Pasu Formation, and Setul Formation.