



WAVE-DOMINATED SHORELINE DEPOSITS IN THE LATE MIOCENE SEDIMENTARY SEQUENCE IN THE MIRI FORMATION NORTH SARAWAK, MALAYSIA

Muhd Nur Ismail*, Abdul Rahman, Sanudin Hj. Tahir

Fakulti Sains dan Sumber Alam, Universiti Malaysia Sabah 88999, Kota Kinabalu, Sabah, Malaysia.

*Corresponding author email: ismail.rakiti89@gmail.com

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ABSTRACT

The research area is located in Miri region, north Sarawak. Observation was focused on selected outcrops along road cuts and beach. The distribution of outcrops is widely distributed at a few localities in Miri region such as Tanjong Lobang, Airport road, Hospital road and Oil Well road. Sedimentary sequences can be traced by facies variations as shoreline environment based on the sedimentary structures. Four facies were identified and characterised successfully in the study area based on their sedimentary structures, namely facies 1: planar cross stratified (PcS), facies 2: swaley cross stratified (ScS), facies 3: swaley-Hummocky cross stratified (SHcS), facies 4: Hummocky cross stratified (HcS) and heterolithic facies (He). Facies evaluation deduced that the sedimentation settings resulted as foreshore, upper shoreface, middle shoreface, lower shoreface and tidal (minor occurrence). Wave-dominated in the upward coarsening interval is unambiguous that representing by abundance of hummocky cross stratification and other storm deposits in the sandstone dominated portions, well-defined swaley cross stratified sandstone interval, and up to several meters thick sets of planar cross beds interval interpreted to have been formed by swash waves. Heterolithic units in this wave dominated sequences are as minor occurrence of tidal influence during fair weather.

1. INTRODUCTION

The study area is enclosed by longitudes between the 113°20' E to 114°20' E and between the latitudes of 4°16' N to 4°24' N (Figure 1). Overall area is covered by a lowland topography except the area towards south which is up to 400 metres high. The accessed outcrops in this study area are mostly exposed along the road and stream rather than coastal areas. From the observation, the most accessible and probably the best exposures are along the road. The study area is largely consists of sandstone and mudstone interbeds. This formation can be traced by facies variation as foreshore to shoreface environments. This observation contributes as a turning point to assess siliclastic lithofacies in the study area and will be described in detail according to parameters.

Wide variety distributions of Upper Miocene shallow marine environment outcrops around Miri region are excellent exposures ever. Observation started at the Canada Hills in Miri town which was one of the main places established for oil exploration and drilling in 1910 to 1971 and stretches along the Miri Hospital road, Oil Well road and Airport roads [1]. These places exposed the well preserved outcrops of Miri Formation rock unit and be a good section for litholog measurements. Moving to the east, some exposures of the Seria Formation cropping out along the Padang Kerbau Road, similar sequence can be observed but incomplete sequence. This research hopes to add on some knowledge about basic sedimentology in Miri Region and give simple guide to young researchers to understand wave dominated sequence in the field.

2. GEOLOGICAL BACKGROUND

The Miri Formation is predominantly arenaceous with a lithology similar to but more marine than the Belait Formation. In Miri Field according to a research paper, this formation was divided into Lower and Upper Miri formation [2]. The Lower Miri consists of a succession of sandstones and shales which are separated in major, well define bodies of similar size, the shales slightly prevailing. Meanwhile, the Upper Miri is more arenaceous; the alternation of sandstone and shales take place more rapidly and is less regular; the sandstone bodies merge more gradually into argillaceous sandstone and sandy or silty shale.

According to a researcher, the rock unit consists of alternation of thick sandstone and siltstone intercalated with little shale [3]. Meanwhile, a research, state that the Miri Formation is predominantly arenaceous, with clay and shale. some explanations by him is similar to another researcher, toward the Miri Formation which is this formation was divided into two lithologic units which is Upper and Lower unit [4,2]. The maximum thickness is over 6000 feet, in the Seria Field and range from 1000 to 4000 feet in the Miri Field.

A new subject related to facies analysis have been recognized and described by a group scientist, based on shallow marine sedimentary structures [5,4,6]. A few sedimentary facies are; through cross bedding, herringbone cross bedding, hummocky-swaley cross bedding, flaser-wavy bedding, lenticular bedding, planar cross bedding and parallel laminated sandstone.

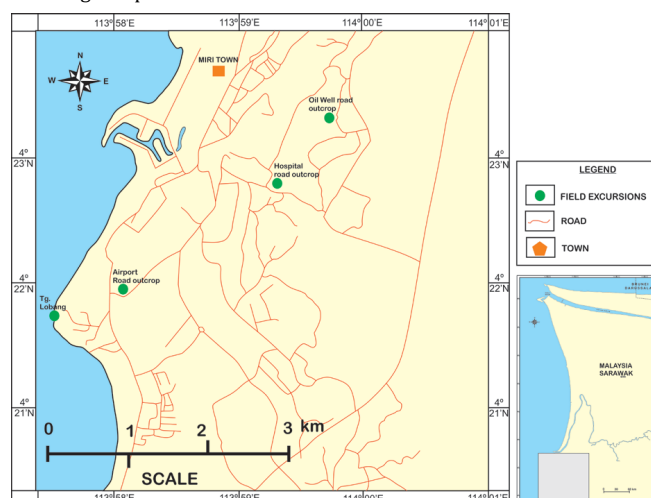


Figure 1: Map of Miri showing the location of study area

3. METHODOLOGY

Methods used in this research are on basic stratigraphy and

sedimentology such as field data collection including site observation, measuring outcrop sections and vertical log analysis. The stratigraphic procedures in this observation were carried out according to International Stratigraphic Guide.

4. RESULT AND DISCUSSION

4.1 Facies Analysis

Five facies are identified on outcrop of the Miri Formation which is divided into major facies and minor facies. The major facies is dominantly exposed and assigned as wave dominated facies and minor facies as tidal facies and is less dominantly exposed. The four major facies are facies 1: planar cross stratified (PcS), facies 2: swaley cross stratified (ScS), facies 3: swaley-Hummocky cross stratified (SHcS) and facies 4: Hummocky cross stratified (HcS).

The heterolithic facies (He) display on a sequence of bed is just a minor unit exposed in a Miri Formation. This facies is represented by percentage of sand and mud lamination and is well known as flaser lamination, wavy lamination and lenticular lamination.

4.2 Heterolithic Facies (He)

4.2.1 Description

Heterolithic facies (He) occur as minor alternate thin layers of flaser, lenticular and wavy beds (Figure 2). This unit is basically composed of siltstone and mudstone ranging from 5 cm to 10 cm thick. It is clearly distinguished between sub-units of flaser, lenticular and wavy according to their ratio of sand and mud. These units occasionally exposed at Tanjung Lobang and Oil well outcrop where they are intercalated with a section of facies 1, facies 2 and facies 3. Meanwhile, other structures displayed as a small scale of hummocky like lenses within the range of 1 cm to 2 cm and parallel lamination mostly illustrated this facies.

4.2.2 Interpretation

Occurrences of heterolithic facies confirm the process of tidally influence condition during fair weather period. Higher content of mud than sand is referred to slow down of current during deposition. Decreasing of wave power during tidal flat will result a heterolithic sequence mostly rich in silt to fine grain size. The small scale of hummocky lenses and parallel lamination represent a continuous reworking by current [7].



Figure 2: Heterolithic facies showing flaser and lenticular bed.

4.3 Facies 1: Planar cross stratified (PcS)

4.3.1 Description

Facies 1 consists of thick planar cross bedded sandstone and thin mudstone bed (Figure 3 (a) and (b)). The individual bed is exposed as a buff thick stacked sandstone ranging between 1m to 3m thick. Based on the vertical litholog constructed from the outcrop at airport road, stacked sandstone bed with planar cross stratified is about 32 meters height (Figure 3). Some part of sandstone beds are closed to amalgamated pattern which is located in an upper part position. A mud unit also exposed as interbedded with sandstone bed with 15 meters thick. The planar sandstone bed is good sorting and ranges from medium to coarse grain size.

4.3.2 Interpretation

Occurrence of thick, amalgamated and stacked planar cross bed is related to high regime of wave in an upper part of a beach profile. A series of planar cross set basically is a result from straight migration of ripple during wave activity. Evidence of good sorting from medium to coarse grain size is due to winnowing process and then could be prolonged process of storm wave.

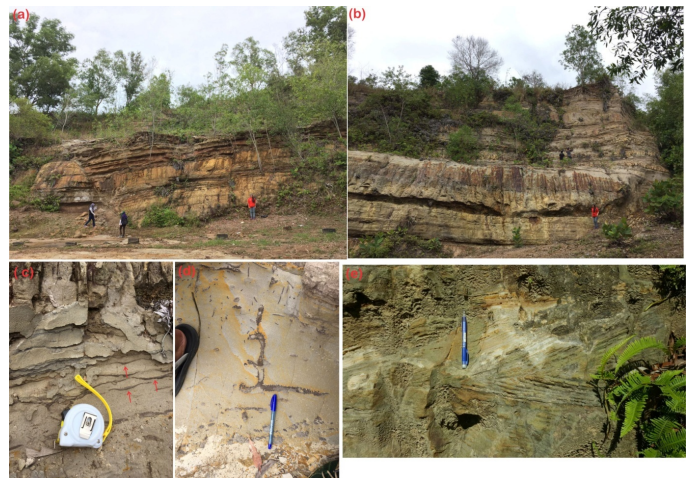


Figure 3: (a) and (b) the Miri Formation outcrops along the Airport road. (c) The flaser lamination structure display by red arrow. (d) Ophiomorpha sp. showing in an individual bed of outcrop. (d) the herringbone cross stratification display on bed.

4.4 Facies 2: swaley cross stratified (ScS)

4.4.1 Description

Facies 2 comprises of moderately to well sorted, fine to medium grain size and range up to 8 meters thick (approximately average of one outcrop). This facies is distributed intermittently around Miri such as at Tanjung Lobang outcrop, Hospital road outcrop and Jalan Oil Well outcrop. Referring to the outcrop at Jalan Oil Well, the swaley bedding ranges from 50 cm to 1 meter thick (Figure 4). At Tanjung Lobang outcrop however, the swaley cross bedding displayed a small scale of cross bedding within the range of 5 cm to 10 cm (Figure 4 (a), (b) and (d)). In this area the grain size is graded upward into medium to coarse grained sandstone.

4.4.2 Interpretation

In such a setting storms would create shallow scours (elliptical to circular in plan view) filled by flattening upward laminae conforming to the shape of the swale that contribute to swaley cross stratification of the rock sequence in the area [8]. Coarsening upward of grain size from fine to medium size showed that increase in flow velocity through time of deposition and is most energetic part of the system [9,10].

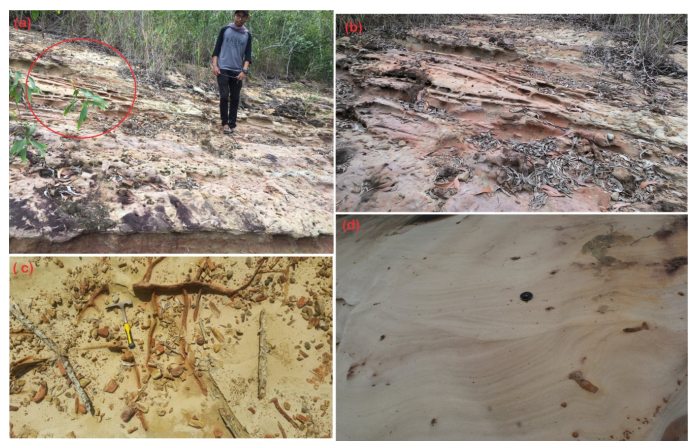


Figure 4: (a) Swaley Cross bed outcrop. (b) Enlargement scale of swaley cross bed. (c) Thalassinoides sp. exposed on sandstone bed. (d) The swaley cross lamination with a few sets of angle.

4.5 Facies 3: Swaley-Hummocky cross stratified (SHcS)

4.5.1 Description

Interbedded sandstone with mudstone, fine to medium grain size, scoured-based and coal lenses are related to facies 3. This facies exposed mostly at Tanjung Lobang outcrop, Hospital road outcrop and Jalan Oil well outcrop (Figure 5). The best exposure of this facies is at Tanjung Lobang outcrops and Jalan Oil Well outcrops. At Tanjung Lobang outcrop this facies is 5 meters thick where the swaley and hummocky (SHcS) lies alternately in one sequence (Figure 5). It shows that the hummocky cross stratified lied at lower bed position and then continuously repeated by medium scale of swaley cross stratified in upper bed position. Whereas at Jalan Oil Well outcrop this sedimentary structure lies in sandstone bed but it is interbedded with mudstone.

4.5.2 Interpretation

Variety of grain sizes, fine to medium interval are resulted from slowing down the energy of wave. The swaley and hummocky occur is due to density current suspension after deposition by continuous storm wave is subjected to the bottom (sediment) and finally create a mould. The mould formed is based on how large a wave action to the sediment during the storm event.

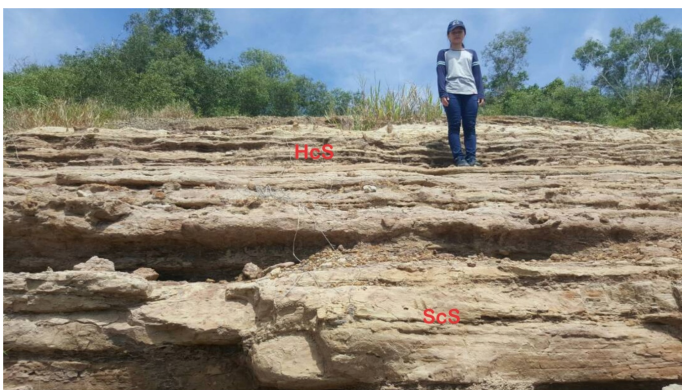


Figure 5: The swaley-hummocky cross stratified is overlying another. It is showing that the swaley cross stratified is overlain by hummocky cross stratified.

4.6 Facies 4: Hummocky cross stratified (HcS).

4.6.1 Description

Facies 4 is recognized as sandstone interbedded with mudstone, bad to moderately sorted grain size and various pattern of sandstone bedding (scour resembling swales bed, contorted bed, disconnected bed, non-homogeneous bed). One of the best exposure outcrop displayed of this facies is at Hospital road outcrop. The upward sequence achieves 30 meters high vertically and 40 meters horizontally (Figure 6 (a)). The bedding geometry showed within the range from 5 cm and up to 1 meter thick. The mudstone is generally abundant in an upper part of the outcrops which is achieved 60 meter thick.

4.6.2 Interpretation

Basically disconnected bed and non-homogenous exposed in a few section in an outcrop is related to natural erosion during storm. According to a researche paper, this hummocky cross bed is result from low net deposition due to sediment by pass but some researcher stated that it may accumulate after repeating storm reworking in high energy setting [11,12].



Figure 6: (a) Large outcrop of Hummocky cross bed, Hospital road. (b) Some macrofossils found in an sandstone bed. (c) Some ophiomorpha sp. lies on sandstone bed.

4.7 Facies Association 1 (FA 1): Tidal

4.7.1 Description

Tidal facies association has an average about 1 m thick. It consists of heterolithic unit with abundant of flaser, lenticular and wavy layers but less exposure. This FA 5 basically is overlain or interbedded with FA 1, FA 2 and FA 4 in an outcrop. The lower and upper boundary is sharp and quite distinct with another hummocky and swaley bed. Bioturbations are most common here with various of ophiomorpha.

4.7.1 Interpretation

Abundance of heterolithic units but less exposure is because of the environment mostly occurring in storm dominated area but some area is influenced by tidal condition. The coastline is exposed to large fair-weather waves but likely will be influenced by storm waves as well. A series of heterolithic unit interbedded with HCS and SCS but in short progradation cycle is because it is minor occurrence during storm wave deposit.

4.8 Facies Association 2 (FA 2): Foreshore

4.8.1 Description

Facies association 1 consists of thick planar cross bedded sandstone. This facies is found as extensively succession that shows medium to coarse grain size in upward sequence of bed. The grain size is generally well sorted. Sedimentary structures in this facies include high angle herringbone structure (Figure 2 (e)) and intermittently interbedded with thin bedded heterolithic unit (flaser) that showing an upward sequence (Figure 2 (c)). Coal lenses are common in this co-set. Burrows and other bioturbations are not too common in this outcrop but some Ophiomorpha sp is present in some part of the sandstone layers (Figure 2 (d)).

4.8.2 Interpretation

The planar cross stratified (PcS) exists in this facies showed a high angle co-set of cross bedding, caused by high regime of storm during phase of deposition. Evidence of good sorting from medium to coarse grain size is due to winnowing process and then could be prolonged process of storm wave. We consider the dominant structures occur in this facies like planar cross stratified and wedging structure is due to wave generated system inner foreshore part of the sedimentary environment. However occurrence of flaser-tidally structure in this sandstone is not exactly in a same system of wave dominated because of it limited appearance and mere a fragment of mud that has been deposited during microtidal event. According to some researcher, mixture of sand and mud in the heterolithic layer will happen due to variation of current or wave activity and sediment supply due to changing of current strength and wave power [9]. Less bioturbation in this facies is because of slowing growth of organism in high wave dominated area.

4.9 Facies Association 3 (FA 3): Upper Shoreface

4.9.1 Description

This facies association comprises of thick cross bedded sandstone which is an individual bedding showed a co-set of high to low angle of cross bedding including through cross bed and swaley cross stratified (ScS) (Figure 3 (a) and (b)). Actually both structures are easy to identify at field due to scale of angle can be distinguishable between them. Bedding plane is scoured, undulating surface and irregular pattern. In a vertical section at Oil well outcrop, this FA 3 is a gradually transition from fine, medium to coarse grain FA 2 sandstone. Boundary between FA 3 and FA 2 is obscured within Oil Well outcrop but can be identified through pattern of cross beded structure. Moderately medium to large burrows of trace fossils like Ophiomorpha sp and Thalassinoides sp are common on sandstone bed (Figure 3 (c)).

4.9.2 Interpretation

Well sorted, variety of grain size from fine to medium grained

sandstone with the existence of swaley cross bedded is a good indicator of upper shoreface environment. Existence of high angle through cross bed indicate high energy of storm occur during deposition. This is due to wave progressively move landward and tend to be asymmetric [13,10]. Sort of bedding plane like scour, undulating surface and irregular pattern is mostly because colliding of storm with sediment bottom during deposition. Moderately abundant of trace fossils with simple burrow systems characterizes upper shoreface environment sandstones [14]. Another indicator is existence of Large to medium trace fossils like Ophiomorpha sp and Thalassinoides sp which mean bigger animals for favourable environment.

4.10 Facies Association 4 (FA 4): Middle Shoreface

4.10.1 Description

This facies association consists of hummocky (HcS) and swaley cross stratified (ScS) sandstone bed. Both structures are overlain each others in one section. Some sections in Oil Well outcrops showed that the swaley cross bed is more thicker than hummocky cross bed which is ranged from 50 cm to 1 meter. Variety of grain size orientation like fine to medium size with rare of coarse grain is dominantly displayed in bed. Mostly beds are showing coarsening upward sequence. Moderate to highly bioturbation of Ophiomorpha and Thalassinoides can be observed in an individual bed.

4.10.2 Interpretation

Existence of hummocky cross stratified (HcS) is overlain by swalley cross stratified (ScS) indicates that the environment is fair-weather wave influenced while the settlement of sand and mud become uncertain. This is supported by one researcher, where swaley is formed between fair weather and storm wave base above hummocky cross stratification but below foreshore sub environment [15]. The variety of grained sizes of sandstone with the existence of swaley cross-stratification which can be seen on Figure 3 is a good indicator for middle shoreface until upper shoreface. The overlying swaley cross-strata are characteristic of a storm-dominated, middle to upper shoreface environment [16]. Moderate to highly bioturbation with abundant of Ophiomorpha and Thalassinoides with complex burrow systems characterize lower shoreface sandstones [14].

4.11 Facies Association 5 (FA 5): Lower Shoreface

4.11.1 Description

This facies association is composed of interbedded hummocky cross bed sandstone (HCS) with mudstone bed. This FA4 is characterized with fine to medium grain size and some of them are well sorted. Large hummocky cross bed can be seen at Hospital road outcrop which is 1 meter thick without displaying any cross set. Bedding plane is mostly showed that non-irregular bottom line with non-homogenous bedding sequence. Relationship between another facies like shelf unit can be seen at Oil Well road which is located below the lower part of the outcrops. Bioturbation is quite intense in every single bed of sandstone, mostly various kind of ophiomorpha sp (Figure 5 (c)). Some macro fossils like shells, mollusc and bivalve also observed in certain part of sandstone and mudstone but partly dissolved (Figure 5 (b)).

4.11.2 Interpretation

The interbedded sandstone with mudstone indicates lateral variation due to decrease of wave energy in a lower shoreface environment. According to a researche paper, the hummocky bed is formed due to combination of scour and deposition operation within brief span of time [17]. Hummocky cross bed also is a result from storm wave and occurs in the transition zone of fair weather wave base and storm wave base. The boundary between the sandstone dominated and the mudstone dominated portions of the succession is sharp and scoured, and is interpreted as the boundary between major subaqueous sandstone set above storm wave-base. Moderate to intense bioturbation with abundant of Ophiomorpha and Thalassinoides with complex burrow systems characterize lower shoreface sandstones [14]. Some macro fossils like shells, mollusc and bivalve within sandstone and mudstone indicate a transition from freshwater to brackish water conditions. This statement is supported by a researcher where they found the freshwater fossils and brackish water fossils within the Miri Formation [1].

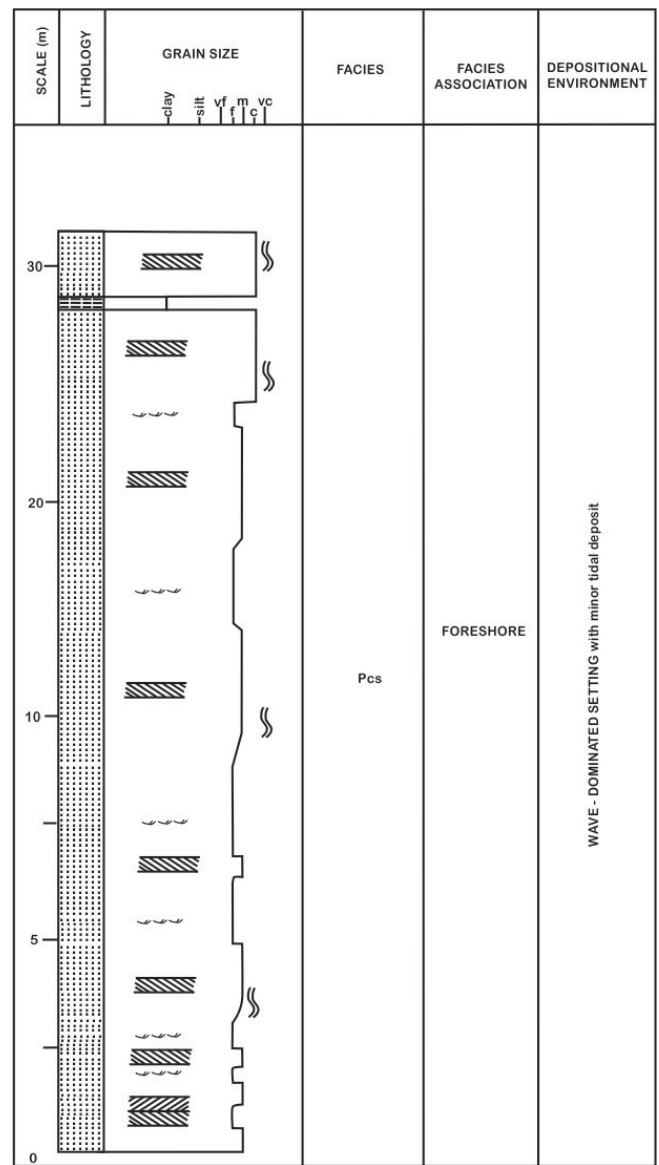


Figure 8: Facies 1, 2, 3 and 4 was exposed as a complete sequence of facies located at Oil Well outcrop.

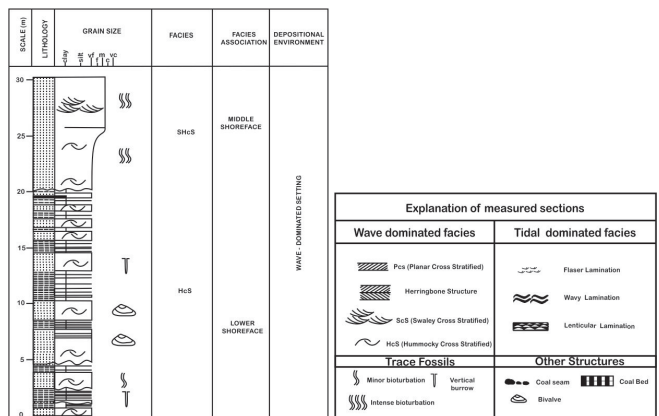


Figure 9: Schematic diagram of litholog from Hospital road outcrop showing facies 3 and 4.

5. ENVIRONMENTAL INTERPRETATION AND MODEL OF WAVE DOMINATED SETTING

The four locality sections given above of the clastic shoreline deposits varies according to the setting of the sediment, the shoreface morphology, the wave climate and the occurrence of storms and floods. On the basis of the dominant sediment distribution, the rock units have been identified four depositional sequences, namely; the lower shoreface, the middle shoreface, the upper shoreface and the foreshore [20]. After examining all the structures and thickness of the rock units of the Miri formation, the depositional history of this

formation then was evaluated. All of this information suggested that the formation has been deposited at a shallow marine environment, specifically at the shoreface depositional environment with the influence of wave and storm events.

According to a researcher, some structures attributed by most workers to storms are hummocky cross-stratification (HCS) [10]. Abundance of HCS is also a good indicator that the sediments have been deposited at the lower shoreface during the event of storms. Basically HCS are indicative of deposition in the lower part of a wave or generally preserved in areas of weak tidal activity that lie below fair-weather wave base and also indicative of deposition in the lower part of a wave or storm dominated shoreface [20].

The variety of grained sizes of sandstone with the existence of SCS which can be seen on Figure 3 is a good indicator for middle shoreface until upper shoreface. In such a setting storms would create shallow scours (elliptical to circular in plan view) filled by flattening upward laminae conforming to the shape of the swale that contribute to SCS of the rock sequence in the area [8]. While the thick mudstone interbedded with the sandstone suggested a fair weather periods which contributes to the formation of sand pit somewhere in the middle of the lower shoreface and the middle shoreface. In many examples from the geological record, swaley cross-stratification sandbodies occur stratigraphically above hummocky cross-stratification sandstones and interbedded mudstones [20].

The abundance of amalgamated SCS and the existence of Planar cross stratification (PCS) in the sandstone give the best indicator of the upper shoreface to foreshore deposits. High regime of current subjected to sediment caused high angle of PCS. While on the upper part of this area is abundance with the medium to coarse grained sandstone, showing the characteristics of the upper shoreface. The sediment typically coarsened toward the upper part of the shoreface, the most energetic part of the system [10, 21].

This section of the outcrops were deposited at the shallow marine environment under the fluctuations of high and low flow wave dominated regimes which can be divided into foreshore (FA 2), upper shoreface (FA 3), middle shoreface (FA 4) and lower shoreface (FA 5) (Figure 5).

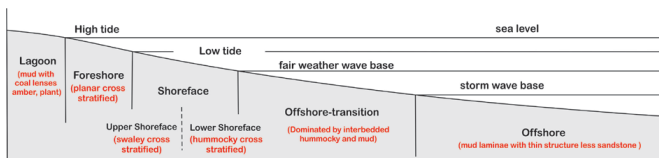


Figure 10: Idealized schematic of the Simplified beach and shoreface environment model.

6. CONCLUSION

As a conclusion, from the detail study of the outcrops of the Miri Formation, five facies were successfully identified during study within Miri region namely Heterolithic facies (He), facies 1: Planar cross stratified (PcS), facies 2: Swaley cross stratified (ScS), facies 3: Swaley-Hummocky cross stratified (SHcS) and facies 4: Hummocky cross stratified (HcS) and Based on facies identified in the Miri Formation, it will result into several facies associations such as tidal (FA 1), foreshore (FA 2), upper shoreface (FA 3), middle shoreface (FA 4) and lower shoreface (FA 5) and According to the result and some information above, the Miri Formation is finally interpreted as dominantly wave dominated setting due to sedimentary structures display and a few parameters behaviour, thus it can be illustrated that has been deposited within a range from foreshore to lower shoreface environment.

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