Eksplorium ISSN 0854 – 1418
Volume 32 No. 2, November 2011: 77 - 90

COMBINED TIDE AND STORM INFLUENCE ON FACIES SEDIMENTATION OF MIOCENE MIRI FORMATION, SARAWAK

***Yuniarti Ulfa [1], Nasiman Sapari [2], Zuhar Zahir Tuan Harith [3]**
[1]School of Physics, Universiti Sains Malaysia, 11800 USM Pulau Pinang, Malaysia
[2]Department of Civil Engineering, Universiti Teknologi PETRONAS, Seri Iskandar 31750 Perak, Malaysia
[3]Department of Geoscience and Petroleum Engineering, Universiti Teknologi PETRONAS, Seri Iskandar 31750 Perak, Malaysia
Email: yuniartiulfa@usm.my

Masuk: 28 September Revisi: 14 Oktober Diterima: 4 November

ABSTRACT

COMBINED TIDE AND STORM INFLUENCE ON FACIES SEDIMENTATION OF MIOCENE MIRI FORMATION, SARAWAK**.** This study was conducted on the sedimentary rocks belonging to the Miri Formation (Middle – Late Miocene). The primary objective of the present study is to provide additional interpretation on the stratigraphy of the Miri Formation in the Miri Field based on the new information gathered from new outcrops in the area. Five outcrops were examined in detail on sedimentology and stratigraphy. Based on lithology, sedimentary structures, bedding geometry and traces fossil, the sediments of the Miri Formation were grouped into fourteen lithofacies. Influence of tide and storm during the depositional processes of the formation were indicated by the group of two main facies associations which are: (i) tide-dominated estuary; and (ii) wave-and-storm dominated facies associations. The tide-dominated estuary system of the Miri Formation are includes variety of sub environments: estuary mouth or tidal channel and sand bars (characterized by trough cross-stratified sandstone with mud drapes facies), estuary channel or upper flow regime of sand flat (characterized by parallel stratified sandstone with mud-laminas facies), mixed-tidal flat (characterized by wavy and flaser bedded sandstone facies), and mud-tidal flat (characterized by rhythmic stratified sandstone-mudstone and lenticular bedding facies). The wave-and-storm dominated varied from lower to middle shoreface (characterized by hummocky cross-stratified sandstone and rhythmic parallel stratified sandstone and laminated siltstone facies), upper shoreface (characterized by swaley cross-stratified sandstone), lower shoreface (interbedded to bioturbated sandstone and siltstone facies), and offshore transitional (characterized by bioturbated sandstone and mudstone interbedding with parallel to hummocky cross-stratified sandstone facies).

Keywords: lithofacies, Miri Formation, stratigraphy, depositional environment

ABSTRAK

PENGARUH PASANG SURUT DAN BADAI TERHADAP FASIES SEDIMENTASI FORMASI MIRI BERUMUR MIOSEN, DI SARAWAK. Penelitian ini dilakukan pada batuan sedimen penyusun Formasi Miri (Miosen Tengah - Akhir). Tujuan penelitian ini adalah untuk mendapatkan interpretasi tambahan pada stratigrafi Formasi Miri di Lapangan Miri berdasarkan informasi baru yang dikumpulkan dari singkapan batuan baru di daerah tersebut. Lima singkapan tersebut diteliti secara rinci berdasarkan aspek sedimentologi dan stratigrafi. Berdasarkan litologi, struktur sedimen, geometri perlapisan dan fosil jejak, sedimen penyusun Formasi Miri dikelompokkan ke dalam empat belas litofasies. Pengaruh pasang surut dan badai selama proses pengendapan formasi diindikasikan dari adanya dua kelompok gabungan fasies utama antara lain: (i) didominasi oleh pasang-surut muara, dan (ii) didominasi oleh gabungan fasies gelombang dan badai. Sistem yang didominasi pasang surut muara pada Formasi Miri meliputi variasi sub-lingkungan: mulut muara atau alur pasang surut, dan gosong sungai (dicirikan oleh fasies batupasir dengan perlapisan saling silang dengan lempung yang mengapung), alur muara atau rezim aliran bagian atas dari dataran pasir (dicirikan oleh fasies batupasir berlapis paralel dengan lumpur berlapis), campuran pasang surut normal (dicirikan oleh fasies batupasir berlapis), dan lumpur pasang surut normal (dicirikan oleh fasies batupasir berlapis ritmik-batulumpur dan perlapisan lenticular). Dominasi pengaruh gelombang dan badai bervariasi dari rendah ke menengah (dicirikan oleh fasies batupasir berlapis silang yang *hummocky* dan batupasir berlapis paralel berulang dan batulanau berlapis), muka pantai bagian atas (dicirikan oleh batupasir berlapis silang yang *swaley*), muka pantai bagian bawah (fasies batupasir dan batulanau yang bersisipan sampai bioturtbasi), dan transisi lepas pantai (dicirikan oleh fasies batupasir bioturbasi dan batulumpur yang bersisipan dengan batupasir berlapis paralel sampai berlapis silang yang *hummocky*).

Kata kunci: litofasies, Formasi Miri, stratigrafi, lingkungan pengendapan

INTRODUCTION

A sedimentary facies is defined as a sediment (or sedimentary rocks) that displays distinctive physical, chemical, and/ or biological characteristics that make it readily distinguishable from the associated facies in the locality[1]. As the product of the deposition, a study on sedimentary facies can simply express the characteristic of a particular depositional environment or a particular depositional process. Based on studies of modern and ancient sedimentary environments, processes and facies, generalized facies models have been proposed to show the lateral and vertical relationships between facies[2].

The Miri Formation, Sarawak, exhibits characteristics of is a siliciclastic sequence consisting of a succession of clay-sand packages that are coarsening upwards[3,4], where its sand member were very important oil and gas reservoirs in the early production in Malaysia. The outcrop localities in the Miri Field have been reported by many authors on sedimentary facies and stratigraphy aspects[3,4,5,6,7,8,9,10]. However new outcrops are exposed resulting from the earth works during the latest urban development in the Miri Town. These outcrops particularly the Boulevard 1 and a thick sequence of vertically dipping section of Hospital Road 2 outcrops reveal new structural and stratigraphic information that indicate more detailed study to be conducted. The presence of hydrocarbon seepages in several outcrops in the area indicates that there may still be accumulations of hydrocarbon in the reservoir also warrant further investigation.

The objectives of this study are (i) to provide latest description of the facies characteristics of the Miri Formation, (ii) identify the depositional environment within the investigated facies and (iii) develop the facies model of the Miri Formation based on the facies association.

STUDY AREA AND METHODOLOGY

The location of this research is in around the Canada Hill area in the northeastern part of Sarawak, Malaysia (Figure 1). It is located between latitudes 4°20'28" N and 4°26'16" N and longitudes 113°57'03" E and 114°03'01" E. Geologically, the area is called Miri Formation and composed of only less than one third of the total Baram Delta Province which is known as the Miri Field[9].

Five outcrops were examined in detail for sedimentology and stratigraphy studies. The choosing of these five outcrops were based on consideration that for stratigraphy and sedimentology purposes, an outcrop need to be well exposed, fresh, showing a thick sequences which make it proper to do a sedimentological logging, and/ or indicate a lithology contact.

Field sedimentological logging was conducted based on the bed thickness, geometry, lithology (includes texture, color, etc.), sedimentary structure and fossils. Based on these sedimentary features, the names of facies were identified called lithofacies. The end product of the logging outcrops is a stratigraphic column, showing the major bedding surfaces and lithofacies of the outcrops. The thickness of the column are varies from 10, 21, 30, 41 and the longest is at the Hospital Road 2 outcrop reach to 250 meters long. Once the stratigraphic column was established, interpretation of the depositional processes was carried out based on the lithofacies analysis. These facies analysis also defined the particular sedimentary environment.

MIRI FORMATION

Rock successions outcropping around the town of Miri, which stratigraphically belonging to the Miri Formation of Middle to Late Miocene, are the uplifted part of the oil-bearing reservoirs in the Miri Field. Artis established a biostratigraphic zonation based on benthonic foraminifera, resulting in the lithostratigraphic scheme which is still in use today[11]. The formation consists predominantly of sandstones with shale and clay restricted mainly to the lower part[3]. The base of Miri Formation forms a conformable transitional contact with the argillaceous Setap Shale and Lambir Formations. The predominated arenaceous Miri Formation is conformably overlain by the Seria Formation.

The maximum total thickness of Miri Formation estimated in Seria Field in Brunei is around 1830 m (Jia & Rahman, 1999). The difference between the Lower and the Upper Miri is not clear in order to be mapped based on the boundary on lithology alone. The Lower Miri, is composed of interbedded sandstone and shale that grades downward into Setap Shale Formation. The Upper Miri is more arenaceous. This unit is composed of more numerous and irregular shale sandstones alternations, with sandstones beds passing gradually into clayey sandstone and sandy or silty shale[4]. From the identification of marine microfauna and lithological characteristics, concluded that these sediments were deposited in a litoral to inner neritic shallow marine environments[3]. The stratigraphic relationship between the Miri Formation and surrounding Formations is shown in Figure 2.

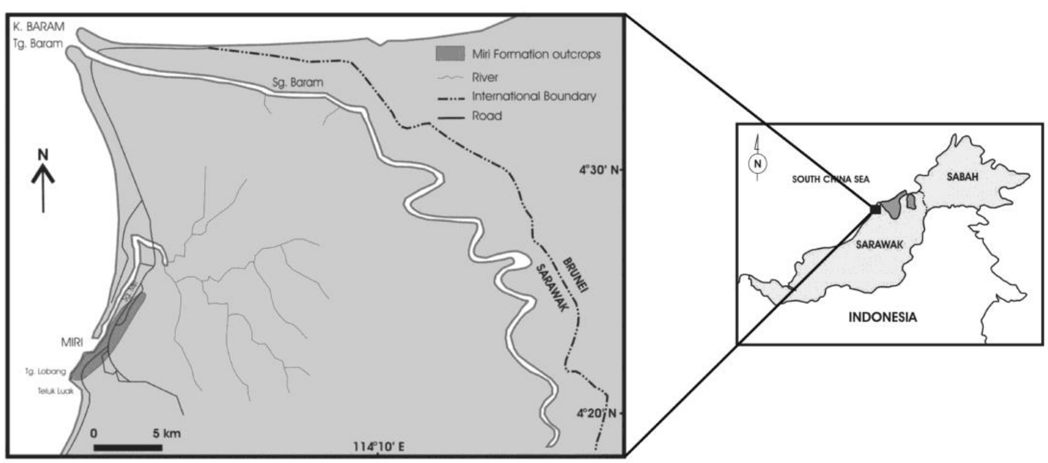

Figure 1. Study area with exposures of Miri Formation at the northeastern part of Sarawak, Malaysia.

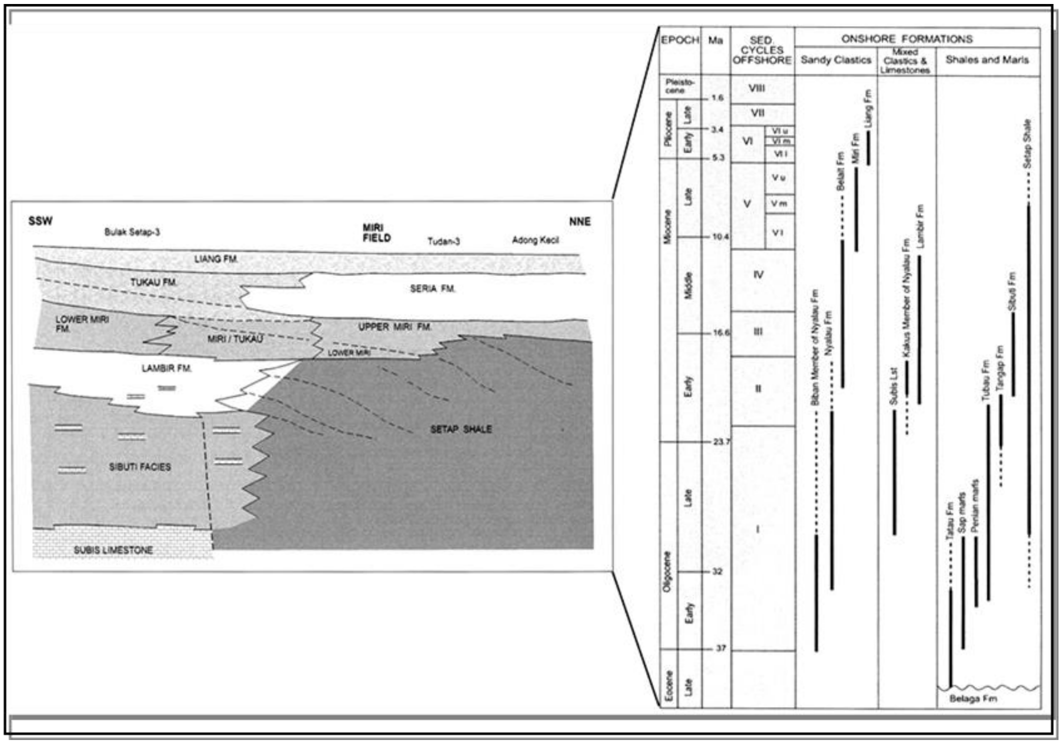

Figure 2. Schematic Stratigraphic successions and correlations of Neogene formations in Miri area and its Schematic correlation between onshore formations and offshore stratigrphy [6] (Tan *et al.*, 1999). (Placed after the figure 2 is called the first time)

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

Fourteen facies were recognized from the field study. The following are description and interpretation of each lithofacies of the Miri Formation in the study area.

Facies A ─ Hummocky cross-stratified (HCS) sandstones

Composed of light gray, fine to very fine grained sandstone with low-angle undulating cross-stratification in association with parallel stratified sandstone and bioturbated siltstone (Figure 3A). The sandstone beds are amalgamated ranges from 0.5 to 5 centimeters thick, and minimum laterally extent up to 400 meters. Few centimeters thick of mudstone separating the hummocky cross-stratified sandstone are common in this facies. Trace fossils include *Ophiomorpha nodosa* and *Skolithos*, but are rare. HCS are known to occur in the lower part of the ancient shoreline sequences, especially in the fine sandstone of shoreface[12]. HCS may be a characteristic of storm-dominated shoreface deposit. Mudstone layers commonly represent post-storm and fair-weather conditions[11]. Facies A is interpreted to be deposited within the lower to middle shoreface environment.

ISSN 0854 – 1418

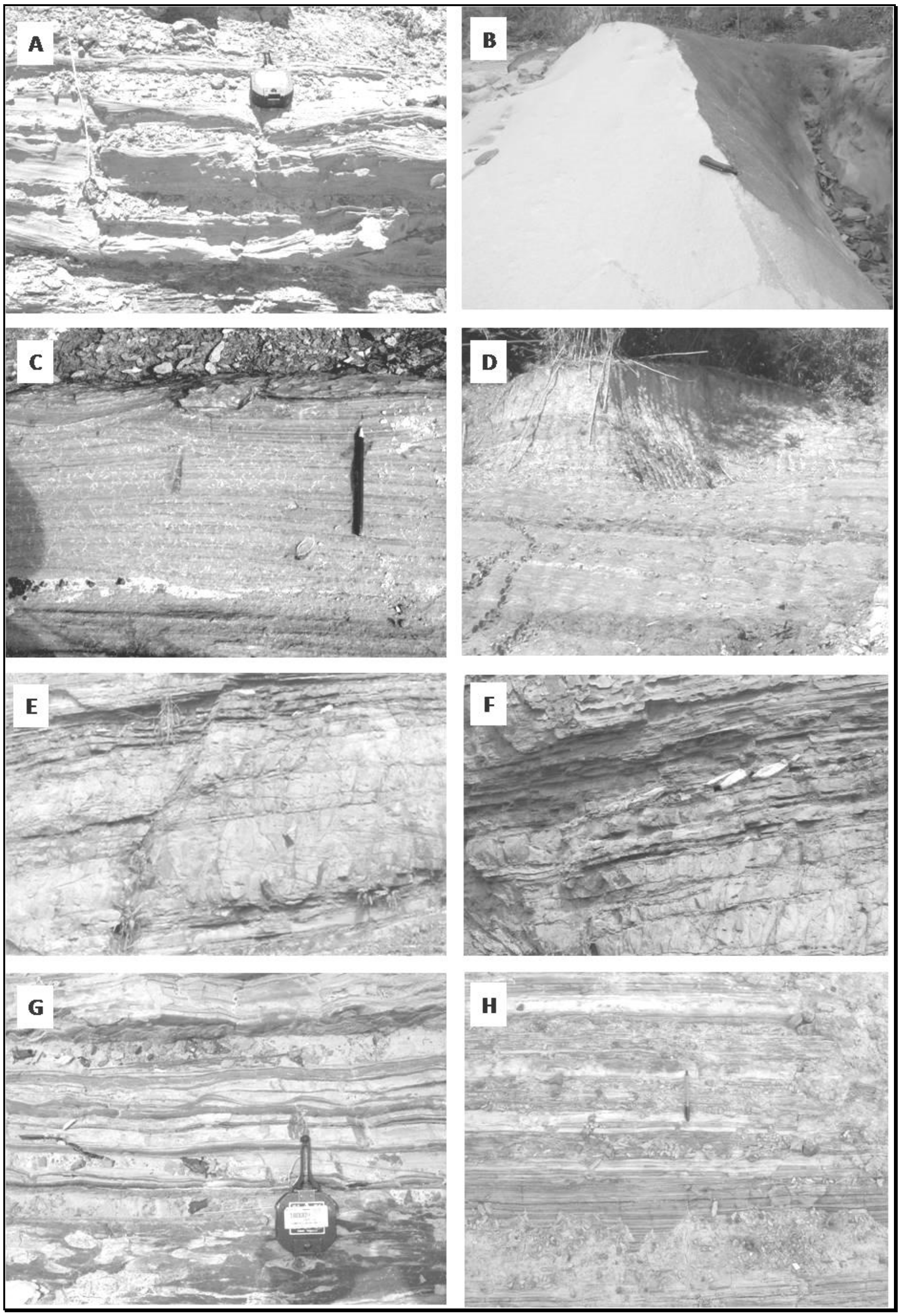

Figure 3. Facies photographs of the Miri Formation (facies A – H)

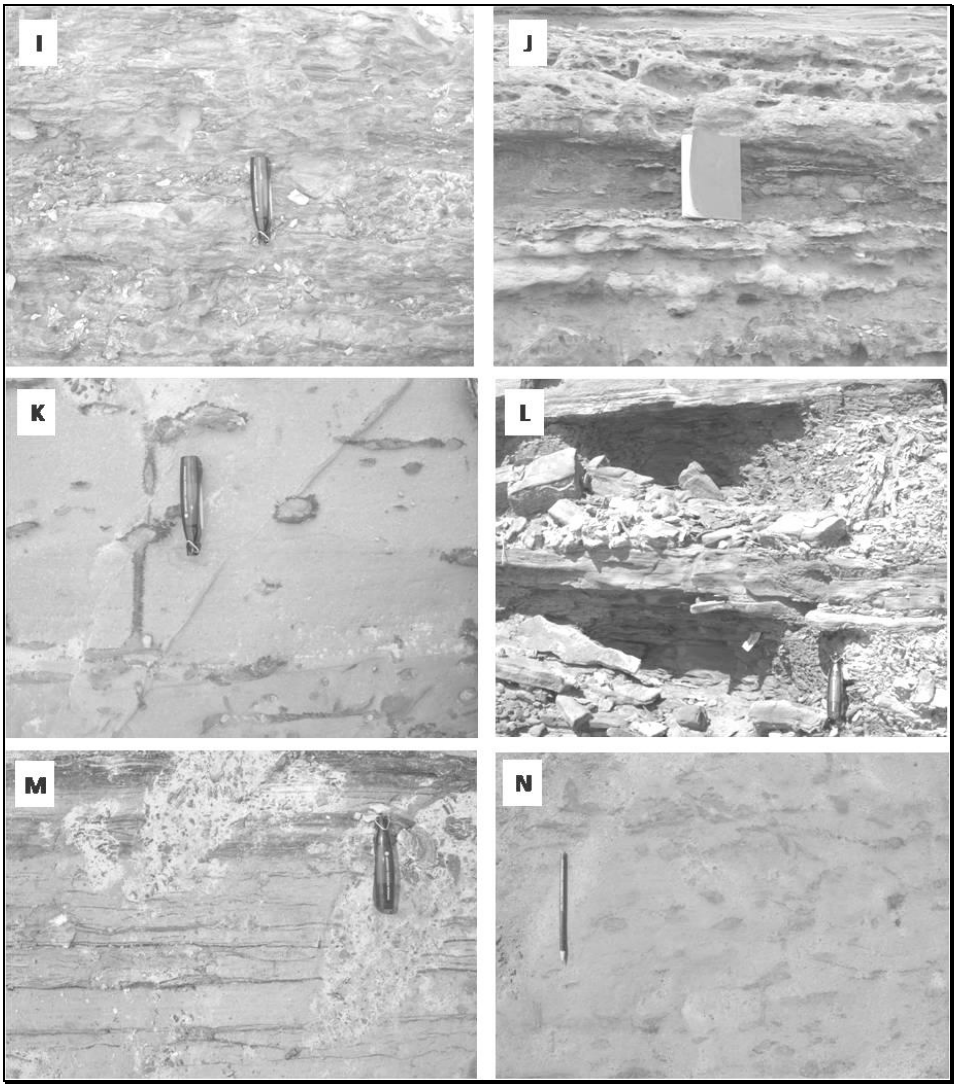

Figure 4. Facies photographs of the Miri Formation (facies I ─ N)

Facies B ─ Massive sandstone

The facies composed of whitish yellow, moderately sorted, medium to coarse-grained sandstone with no internal structure (Figure 3B). The thickness of facies B ranges from 20 centimeters to 5 meters thick. This beds laterally extent up to 30 meters. Due to the absence of biologic activity, the massive structure of facies B could be produced by very rapid sedimentation where the material was dumped as a homogenous mass. Facies B occurs as single bed within tide-generated facies. It is suggested that storm could have reworked and transported sand in very shallow water, creating a density current. Therefore, estuary mouth is the suitable environment for facies B to be deposited by a homogenous mass flow caused by storm in tidally influence environment.

Facies C ─ Swaley cross-stratified (SCS) sandstone

It is consisted of light gray, well to moderately sorted, fine to medium-grained sandstone with no mudstone partings (Figure 3C). The sandstone body thickness ranges from 0.5 to 3 meters, has a minimum lateral extent up to 100 meters. In this facies, sandstone is commonly associated with parallel-stratified siltstone. Trace fossils include *Ophiomorpha nodosa* and *Skolithos*, are very rare but become very intensive at the base. Flat bedding which is associated with swaley cross-stratification, probably formed in shallower water than hummocky cross-stratification, perhaps in outer shoreface zone[2]. Compared to facies A, the facies C is interpreted as having been formed at upper shoreface environment.

Facies D ─ Rhythmic parallel stratified sandstone and laminated siltstone

This facies is characterized by alternation between whitish yellow, moderately sorted, fine-grained sandstone and light brown, parallel laminated siltstone (Figure 3D). The common sedimentary structures were observed in this facies is faint parallel lamination. The sandstone and siltstone beds thickness ranges from 0.5 to 1 centimeter, and laterally continuous up to 10 meters. Alternation of parallel-bedded sandstone in which burrows are rare to absent and parallel-stratified sandstone is generally indicative of a moderate energy environment and the presence of mudstone laminae indicate periods of low energy environment. These suggests considerable variation in sedimentation rates, probably associated with storm or fair-weather deposition., thus facies D is interpreted as having been formed at upper to middle shoreface environment.

Facies E ─ Trough cross stratified sandstone with mud-drapes

Facies E consists of light yellow, fine to medium-grained sandstone with medium to large-scale trough cross-stratification (Figure 3E). Other sedimentary structures that can be observed locally present in the sandstone bodies are tabular cross bedding and planar cross bedding. The sandstone bed ranges from 0.5 to 2.5 meters thick, with minimum lateral extent up to 10 meters. The sandstone beds is amalgamation, where the thickness decreases upwards. In some places, trough cross-beddings are present without any mud drapes. Bioturbation is common, and in places abundant. The common trace fossil recorded from this facies includes *Ophiomorpha*. A specific feature in this facies is characterized by the present of herringbone structure at the middle and lower part of the facies. In between a set of herringbone structure, usually mud drapes are found. Facies E is interpreted to be formed at subtidal zones with channels and bars in contact with the shallow marine environment. Estuary mouth in a tide-dominated estuary would be the best condition for this depositional condition.

Facies F ─ Parallel stratified sandstone with mud-laminas

This facies (Figure 3F) is composed of light yellow to gray, fine to very fine grained, and well to moderately sorted sandstone. The sandstones show parallel stratification to low angle cross-stratification. The bed ranges from 0.25 to 3 meters thick, with minimum lateral extent up to a hundred meters. This facies is marked by the presence of numerous mud laminas of 0.5 to 3 cm thickness. Trace fossil is sparse. The common one is *Ophiomorpha* species. The thickness of facies F ranges from 20 centimeters to 2 meters thick and laterally extent up to 30 meters. Facies F locally shows sharp contacts with the underlying facies E. In some places, facies F overlies mudstone beds of facies I. Parallel stratifications may be formed in sandy tidal flat in the headward portions of macrotidal estuaries that most likely record upper plane bed conditions[14]. A number of organic remains and burrows may be present in estuaries and increasing in the direction of open sea[12]. This facies is interpreted as upper flow regime of sand flat or estuarine channel.

Facies G ─ Wavy-bedded sandstone

Facies G comprised of alternation between light yellow, fine to medium-grained sandstone and gray mudstone (Figure 3G). The sand layers are about 2 to 10 centimeters thick while the mud layers range from a lamina thick to 2 cm. Wavy bedded sandstones are laterally continuous up to few to ten meters. Sedimentary structures of asymmetrical to nearly symmetrical ripples were displayed in this facies. Trace fossils are absent. Facies G gradually overlies facies I (lenticular bedding), facies M (flaser bedding) and or facies H (rhythmic stratified sandstone and mudstone). The formation of wavy bedding requires conditions where the deposition and preservation of both sand and mud are possible. All these indicate that wavy bedded facies could be formed in mixed-tidal setting.

Facies H ─ Rhytmic stratified sandstone and mudstones

Facies H is characterized by regular alternation of very fine-to-fine grained, parallel and undulating, thin sandstone layers with mud layers (Figure 3H). The sandstone is commonly in sharp contact with mudstone. The thickness of sands varies from less than 1 centimeter to 12 centimeters, while the mud layers ranges from less than 1 centimeter to 2 centimeters. Parallel and ripple cross-laminations are common in the sand layers. Loading cast and flame structures are very common at the base of sand beds. Lenticular bedding is locally present in this facies while flaser and wavy-bedding are relatively abundant within this facies. Trace fossils are rare in this facies. This facies is interpreted as having been formed at muddy to mix tidal flat environment.

Facies I ─ Lenticular bedding

Individual sand lenses, typically with internal (micro) cross lamination within a mud unit, characterize this facies (Figure 4A). The sand lenses are commonly in sharp contact with mudstone. The sand lenses are commonly discontinuous and isolated not only in a vertical but in a horizontal direction, giving the appearance of sand floating in mud. Facies I thickness ranges from a few centimeters to 200 centimeters. Trace fossils are rare in this facies. Facies I is interpreted as having been formed in subtidal or intertidal (muddy flat) zones.

Facies J ─ Interbedded to bioturbated sandstone and siltstone

Facies J is characterized by alternations between light yellow, moderately sorted, fine grained sandstone and light whitish-yellow medium grained bioturbated siltstone (Figure 4B). Parallel laminations of mudstone commonly occur within this facies. The contact between sandstone and siltstone is commonly destroyed by organic activity (bioturbation). The thickness of sands varies from 5 centimeters to 30 centimeters while the silt ranges from 5 centimeters to 20 centimeters. Sand beds are laterally continuous, up to ten meters. Facies J possibly have been formed in shoreface. In addition, a fair weather condition is indicated by the occurrence of siltstone and mudstone interbedding, which may record the latest stage of sediments fallout after storm events. The present of moderately to high bioturbated sandstone and siltstone indicated deeper part of the shoreface[12]. Thus, facies J is interpreted as having been formed in lower shoreface.

Facies K ─ Bioturbated sandstone

Facies K is composed of gray, massive and moderately to highly bioturbated sandstone (Figure 4C). Trace fossils, which includes *Ophiomorpha* and *Chondrites*, are abundant in this facies. The thickness of this facies varies from few centimeters to 75 centimeters. Parallel lamination structure is commonly found within the sandstone bodies. Facies K commonly associates with wavy bedded sandstone (facies G), lenticular bedding facies (facies I) and flaser bedding (facies M). Facies K is interpreted as having been formed in lower shoreface environment.

Facies L ─ Mudstone interbedding with parallel to hummocky cross-stratified sandstone

Facies L is composed of mudstone interbedding with light gray medium to thick sandstone beds (Figure 4D). The sandstone is fine to very fine grained and moderately sorted. The sedimentary structures that can be observed within the mudstone include parallel lamination and hummocky cross-stratification structures in the thick sandstone beds. In contrast to facies A, the sand layers are thicker in this facies ranges from 10 centimeters to 50 centimeters thick. Mudstone beds which separating the hummocky cross-stratified sandstone thickness ranges from 15 centimeters to 70 centimeters thick. The sandstone beds are laterally extensive up to hundred meters, possibly with sheet like geometry, but display variation in thickness with sharp lower contacts. Trace fossil includes *Ophiomorpha* and *Skolithos* are locally preserved at the base of the sandstone beds. The thickness of facies L ranges from 1 meter up to 5 meters. Facies L reflects a fair-weather condition, which is indicated by the occurrence of sandstone and mudstone interbedding. The occurrence of hummocky cross-stratification indicates a storm origin of the sandstone beds. Such a character could be produced in environment where mud deposition is going on and being interrupted by occasional heavy storm, depositing sand layers[12]. Therefore, facies L is interpreted as having been deposited in offshore transitional environment.

Facies M ─ Flaser bedded sandstone

Facies M is characterized by wavy or lenticular silt or fine sand with thin wavy to wispy partings of mud (Figure 4E). The preserved mudstone is commonly discontinuous. The sand layers are about 2 to 10 centimeters thick, while the mud layers range from a lamina thick to 1 centimeter. Flaser bedded sandstones are laterally continuous up to few to ten meters. Sedimentary structures of asymmetrical to nearly symmetrical ripples are displayed in this facies. Trace fossils are absent. This facies may reach thickness of up to 50 centimeters. It was interpreted form at tidal flat environment

Facies N ─ Bioturbated siltstone

This facies have similar characteristic to facies K. Facies N is composed of dark gray, massive, moderately bioturbated siltstone (Figure 4F). *Ophiomorpha* is the most common trace fossils found in this facies. The facies thickness varies from 10 centimeters to 5 meters. It is commonly overlies the facies G, facies I and facies M or gradually changes to facies K (bioturbated sandstone). Facies N reflects moderate energy environment. Bioturbation is commonly part of shoreface environment, but compared to the facies association with wavy bedded sandstone, it is much more as indication of tidal environment. Most parts of the tidal flat surface sediments are highly bioturbated by benthonic organisms[12]. Bioturbation in mud flats is generally strongest, weaker in mixed flats, and weakest in sand flats. Therefore, it is indicated that facies N could be formed in tidal flat, specifically in sand to mixed-flat setting.

FACIES ASSOCIATION

Several different facies are commonly grouped together in distinct unit in order to define the characteristic of a particular depositional setting and/ or mode of formation[1]. Two facies associations of the Miri Formation in the Miri Field have been identified, these are tide-dominated estuary and wave-and-storm dominated facies associations. Descriptions and interpretation of these facies associations are briefly explained below.

Tide-dominated estuary facies association (FA-1)

FA-1 is interpreted to comprise tidal deposit caused by the presence of tidal imprints within this facies group, such as tidal cross-bedding with mud laminas, bidirectional (herringbone) cross-bedding, rhythmic stratification between sandstone and shale or mudstone, flaser, wavy and lenticular bedding. In general, FA-1 ranges from 25 centimeters up to 3.5 meters. It shows repeated fining upwards or progradation succession (Figure 5).

In Miri outcrops, a complete tide-dominated estuary facies association commonly started with multiple stacking of trough cross-stratified sandstone (facies E) or parallel stratified sandstone with mud laminas (facies F). These facies commonly formed near the head of estuarine channel or upper flow regime sand flat (subtidal). Gradual change upwards to flaser bedded sandstone (facies M) or wavy bedded sandstone (facies G) indicates that the depositional environment was tidal flat (intertidal) with shallowing upwards process because of relative sea level drop. Further, fining upwards continued by the deposition of rhythmic stratification (facies H) or mud deposits with relatively little sand (facies I). The fining upward of tidal facies succession as a progradational tidal depositional system from subtidal to intertidal and tidal flat zone[14].

Wave-and-storm dominated facies association (FA-2)

FA-2 is interpreted to comprise storm or fair-weather deposit constitute the most seaward components of the shoreline system. Swaley and hummocky cross-stratified sandstone in FA-2 record deposition by storm processes above storm-wave base (Figure 6). The presence of mudstone and siltstone in between sandstone beds in FA-2 record deposition from suspension below fair-weather-wave base. Tide-generated structures are absent in this facies association. In general, the composite thickness of FA-2 ranges from 8 meters of up to 15 meters. It shows repeated coarsening upwards exhibiting a transition from sands in the lower shoreface, to alternating sands and mud below fair-weather wave base, to muddy facies below storm wave base. In detail, a complete wave-and-storm dominated facies association is commonly characterized by interbedded between bioturbated sandstone and siltstone (facies J), and mudstone interbedding with parallel to hummocky cross-stratified sandstone (facies L). These facies suggests an environment below or just above the fair-weather wave base and above storm-wave base or offshore transitional. Another characterization of this facies association is presented by high bioturbated sandstone (facies K), hummocky cross-stratified sandstone (facies A), swaley cross-stratified sandstone (facies C) and rhythmic parallel stratified sandstone and siltstone (facies D). These facies suggests an environment between upper to middle shoreface. All the evidences indicate that the depositional processes in this environment characterized by an increase in sand beds thicknesses but tend to decrease landwards in mud preservation. Toward the deeper part of the shoreface, cross bedding is very rare. Here laminated sand is more dominant[12]. At the same time, the degree of bioturbation also increases. Normally, sand is mainly deposited in the upper shoreface and the foreshore. During heavy storms, a lot of sand is eroded on the foreshore and upper soreface and is taken into suspension by turbulent water. The suspended sand is brought to the lower shoreface and deposited as evenly laminated sand. The offshore transition extends from mean storm wave base to mean fair weather wave base and therefore characterized by alternations of high and low energy conditions. During fair weather, fine grained sediments settle from suspension and the bottom of sediments are bioturbated. During storms, the bottom is affected by oscillatory and shoaling waves, supplemented by storm-generated currents[15]. The nearshore zone extends from mean storm wave base to fair weather wave base. It comprises a shoreface, below mean low water level and a foreshore between mean low water and mean high water level.

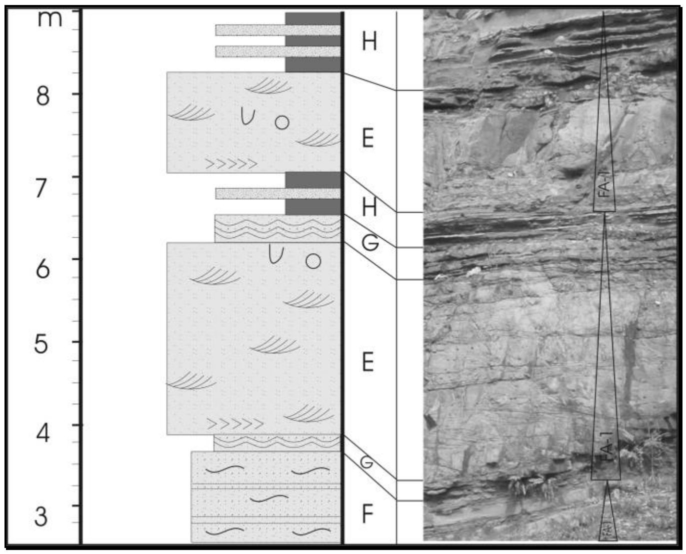

Figure 5. Repeated fining upwards cycles tide-dominated estuary facies association (FA-1) from one of Miri outcrops.

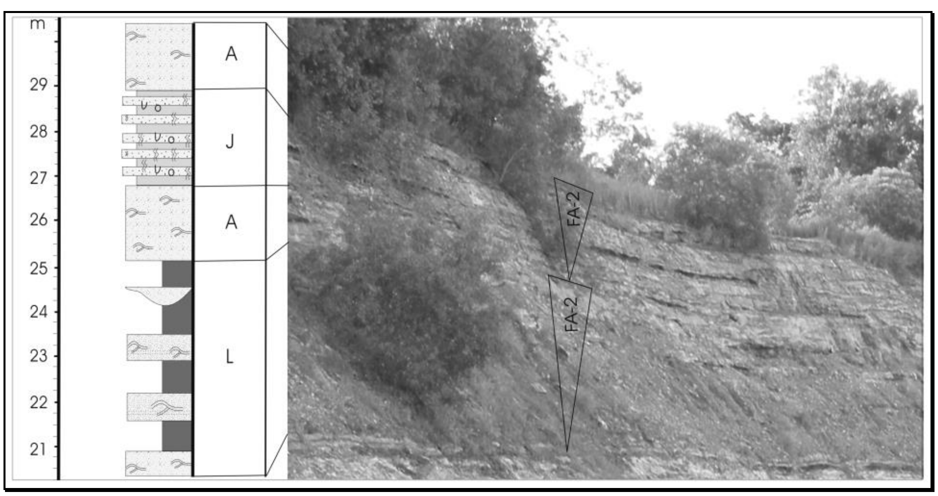

Figure 6. Repeated cycle of wave-and-storm dominated facies association (FA-2) from one of Miri outcrops.

CONCLUSIONS

Based on lithology, sedimentary structures, bedding geometry and traces fossil, the sediments of the Miri Formation were grouped into fourteen lithofacies. Two facies associations of the Miri Formation in the Miri Field have been identified which represent the major paleoenvironment of the investigated Miri Formation. These are: (i) tide-dominated estuary (FA-1) and (ii) wave-and-storm dominated (FA-2) facies association. These facies association thus characterized the combined tide and storm influence on facies sedimentation of Miocene Miri Formation, Sarawak where tide-dominated estuary model of the Miri Formation includes: (i) estuary mouth or tidal channel and sand bars (facies E); (ii) estuary channel or upper flow regime of sand flat (facies F); (iii) mixed-tidal flat (facies G and facies M); and (iv) mud-tidal flat (facies H and facies I) which generally showing alternating sand or mud layering in different dimension related to the tidal phases of alternating current and slack water activity and the storm-and-wave dominated model of the Miri Formation includes: (i) lower to middle shoreface (facies A and D); (ii) upper shoreface (facies C); (iii) lower shoreface (facies J); and (iv) offshore transitional (facies L and facies K). In general, the depositional processes in shoreface is mostly controlled by waves, and commonly decreased by the increasing of the water depth. Upper shoreface (0 to 2 meters water depth) indicates high wave energy and low organism activity, reflected by the deposition of facies C. Lower wave energy but higher organism activity, reflects by the deposition of facies A and D in the middle to lower shoreface (below water depth of 2 meters). Lower shoreface (facies J) reflects low wave energy and high organism activity. The lower shoreface and offshore zones are not affected by waves thus fine-grained sediment is deposited from suspension with possibility be reworked. The deposition of facies L and facies K in the offshore transitional reflects an alternation periods of fair-weather and storm activities.

ACKNOWLEDGMENT

The authors wish to acknowledge the support from Universiti Teknologi PETRONAS Short Term Research Funding (STIRF) for this study.

REFERENCES

1. STOW, D.A.V., “Sedimentary Rocks in the Field: A Colour Guide”. Manson Publishing, London, 320 pp, 2005.
2. TUCKER, M.E., “Sedimentary Petrology”, 3rd Edition. Blackwell Science. Oxford, 262 pp, 2001.
3. LIECHTI, P., ROE, F.W. & HAILE, N.S., “The Geology of Sarawak, Brunei, and the Western part of the North Borneo”, Bulletin of Borneo Geological Survey,3, 1960.
4. WILFORD, G.E., “The Geology and Mineral Resources of Brunei and Adjacent Parts of Sarawak with Description of Seria and Miri Oilfields “, Borneo Geological Survey Dept., Brunei Press Limited, 1961.
5. BANDA, R.M., “The Geology and Planktic Foraminiferal Biostratigraphy of the Northwest Borneo Basin, Sarawak, Malaysia”. Unpublished Ph.D Thesis, Geoscience Program, University of Tsukuba, 148pp, 1998.

6. TAN, D.N.K., ABDUL HADI. A.R., AZLINA A., BAIT, B. & CHOW, K.T., "The Petroleum Geology and Resources of Malaysia. PETRONAS, West Baram Delta", In: Chapter 13 of Kuala Lumpur, pp. 291-342, 1999.
7. MAZLAN MADON, "The Petroleum Geology and Resources of Malaysia. PETRONAS Tectono-Stratigraphic Provinces, and Structural Styles, Basin Types", In: Chapter 5 of, Kuala Lumpur, pp. 79-111, 1999.
8. TATE, R.," The Geology of Borneo Island. Geological Society of Malaysia", 2001.
9. ABEIDA, H.S.A., "Reservoir Characterization and Some Petrophysical Properties of the Miri Formation (Middle Miocene) Miri, Sarawak". Unpublished M.Sc. Thesis, School of Physics, Universiti Sains Malaysia, P. Pinang. 198 p, 2006.
10. JIA, T.Y. & RAHMAN, A.H.A., "Comparative Analysis of Facies and Reservoir Characteristics of Miri Formation (Miri) and Nyalau Formation (Bintulu), Sarawak". Bulletin of the Geological Society of Malaysia, 55, 39-45, 2009.
11. SCHUMACHER, P.V," The Miri Field", Unpublished Shell Oilfields Internal Report, 1941.
12. REINECK, H.E. & SINGH, I.B.," Depositional Sedimentary Environment: with Reference to Terrigenous Clastics", 2nd Revised and Updated Edition. Springer-Verlag. New York, 549 pp, 1980.
13. READING, H.G., "Sedimentary Environments: Processes, Facies and Stratigraphy. Blackwell Science", Oxford, 569 pp., 1996.
14. DALRYMPLE, R.W., "Tidal Depositional Systems", in R.G. Walker & J.N. Plint eds., Facies models response to sea level change, Geol. Assoc. Canada, p. 195-218, 1992.
15. WALKER, R.G.," General Introduction: Facies, Facies Sequences and Facies Models, in Walker, R.G. eds., Facies model 2nd ed., Geol. Assoc. Canada, p. 1-9, 1984.