

Sedimentology facies of the Tatau Formation, Tatau-Bintulu Road transect, Sarawak, Malaysia

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Abstract: Sarawak is divided into four zones, namely the West Borneo Basement, Kuching Zone, Sibul Zone and Miri Zone. The Sarawak Basin in the state covers both onshore and offshore areas, divided into several geological provinces which are of Palaeogene to recent age. On the shelf of the basin, sedimentary succession exceeds 12 km thick (Tan & Lamy, 1990). The study area which is located between Tatau and Bintulu, consists of sediments which are Neogene in age. Sedimentology and stratigraphy study was carried out on the Neogene sedimentary succession at the study area, which stretches around 10 km to 15 km northeast of Tatau town and southwest of Bintulu town. A total of four outcrops were studied. The results are based on field survey of the outcrops across the study area and laboratory analysis of the collected sedimentary samples from the field. The facies analysis results in the identification of seven facies which can be are sand-dominated facies and mixed sand and mud-dominated facies. The sedimentary successions were deposited in an estuarine-inner shelf region.

Keywords: Sarawak basin, early Neogene, Miri Zone, Tatau Formation

Abstrak: Sarawak dibahagikan kepada empat zon iaitu West Borneo Basement, Zon Kuching, Zon Sibul dan Zon Miri. Lembangan Sarawak dibahagikan kepada beberapa wilayah geologi yang berumur Paleogen sampai sekarang, meliputi kedua-dua kawasan di dalam dan luar pesisir. Di pelantar lembangan, ketebalan sedimen melebihi 12 km (Tan & Lamy, 1990). Kawasan kajian yang terletak di antara Tatau dan Bintulu terdiri daripada sedimen yang berusia Neogene. Kajian sedimentologi dan stratigrafi telah dijalankan di kawasan kajian yang terbentang di sekitar 10 km hingga 15 km timur laut dari bandar Tatau dan barat daya dari bandar Bintulu. Sebanyak empat singkapan telah dikaji. Keputusan adalah berdasarkan kajian di singkapan dalam kawasan kajian dan analisis di makmal menggunakan sampel yang dikumpul. Melalui analisis fasies, tujuh jenis fasies telah dikenal pasti di mana fasies tersebut boleh dikategorikan sebagai fasies yang didominasi oleh pasir dan fasies yang didominasi oleh pasir dan lumpur. Sedimen telah ditanapkan di kawasan muara-dalaman.

Kata kunci: Lembangan Sarawak, Neogene awal, Zon Miri, Formasi Tatau

INTRODUCTION

The Sarawak Basin exhibits a complex geology and there has been insufficient sedimentological data for interpretation. Although many earlier studies have been carried out since the early 50's, the understanding of the geological and tectonics history of Sarawak is still unclear (Tongkul, 1999). This study tends to focus its attention to the Neogene sedimentary rocks around Tatau area which is less explored. Existing regional geological information of the area can be obtained from some previous studies, but there have been numerous good sedimentary rock exposures throughout the years (Tongkul, 1999). Hence, there is a need to re-examine the early geological evolution of the area.

The focus of this study is the site situated on the northeastern part of the Tatau area, onshore between Tatau town and Bintulu town of Sarawak. In this study, emphasis is on the sedimentology and stratigraphy (facies) of the study area. This research documents the

types of sedimentary rocks or facies, sedimentary layers and illustrates the stratigraphic architecture of the area.

The main objective of this study is to reconstruct the depositional history of the early Neogene Sarawak Basin, to reveal the types of deposited sediments and their sequence of deposition. The specific objectives of this study are: (1) to reveal the successions of sedimentary facies, (2) to deduce the facies associations in the formation and (3) to determine the depositional environment of the study area.

GEOLOGICAL SETTING AND STUDY AREA

Geological setting of Sarawak

According to various geological histories, Sarawak is divided into four zones including the West Borneo Basement, Kuching Zone, Sibul Zone and Miri Zone. In the Kuching Zone, most of the zone is cropped out by Paleozoic and early Mesozoic rocks. Most of the rocks in the central and northern part of Sarawak are of Late

Mesozoic and Cenozoic age. In the Sibu Zone, the rocks are almost Upper Cretaceous to Upper Eocene in age. The Miri Zone is the youngest zone, underlain by Upper Eocene to recent strata. From Kuching to Miri zone, there is a decrease in stratigraphic and structural complexity towards the east.

The West Borneo Basement is the eastwards extension of Sundaland. It is the pre-Tertiary continental core of Borneo with the Middle Jurassic to Late Cretaceous plutonic rocks intruding the oldest rocks of Middle-Upper Carboniferous to Permian basement rocks. Hutchison (1989, 1996) summarized the geology of the West Borneo Basement. Middle-Upper Carboniferous to Permian mica schists, hornfels and metaquartzites are the oldest rocks in the zone. The Middle Jurassic to Late Cretaceous plutonic suites intruded these rocks.

Kuching Zone, located at the southwestern part of Sarawak, is believed to be the northward extension of the West Borneo Basement (Hutchison, 1989). This zone consists of sub-Upper Cretaceous shelf deposits where the central region of Kuching which consists of marine limestones is overlain mainly by siliciclastic sequences and minor carbonates. The Lupar line marks the boundary between Kuching Zone and Sibu Zone. This zone is overlain by interbeds of deep-sea sediments and pillow basalt and intruded by gabbro.

Deepwater sediments of the Rajang Group which have been deformed into the Rajang Fold-Thrust Belt underlie The Sibu Zone. Lupar, Belaga and part of Danau Formation are part of Rajang Group (Hutchison, 1996). The zone consists of intensely folded, thrust and low-grade metamorphosed turbidites of Late Cretaceous to Eocene age (Haile, 1969). The Tatau-Mersing Line separates the Sibu Zone and Miri Zone. According to Hutchison (1989), the structurally complex zone consists of Paleocene to Eocene ophiolitic rocks.

Further to the north and east, shallow marine shelf sediments dominate the Miri Zone. This structurally complex zone is dominated by Palaeocene to Eocene ophiolitic rocks (Hutchison, 1989). Some of the rocks are basalt, tuff and radiolarian chert. The Tatau-Mersing Line is a major unconformity between the Rajang Group and the Upper Eocene-Recent sediments of the Miri Zone that overlie the group. Rocks in this zone represent the lower part of the Sarawak Basin succession which prolongs offshore into the continental margin.

Study area

Figure 1 shows the location of the study area. The study area is located between Tatau and Bintulu (along Tatau-Bintulu Road). A total of four outcrops were studied (Figure 1).

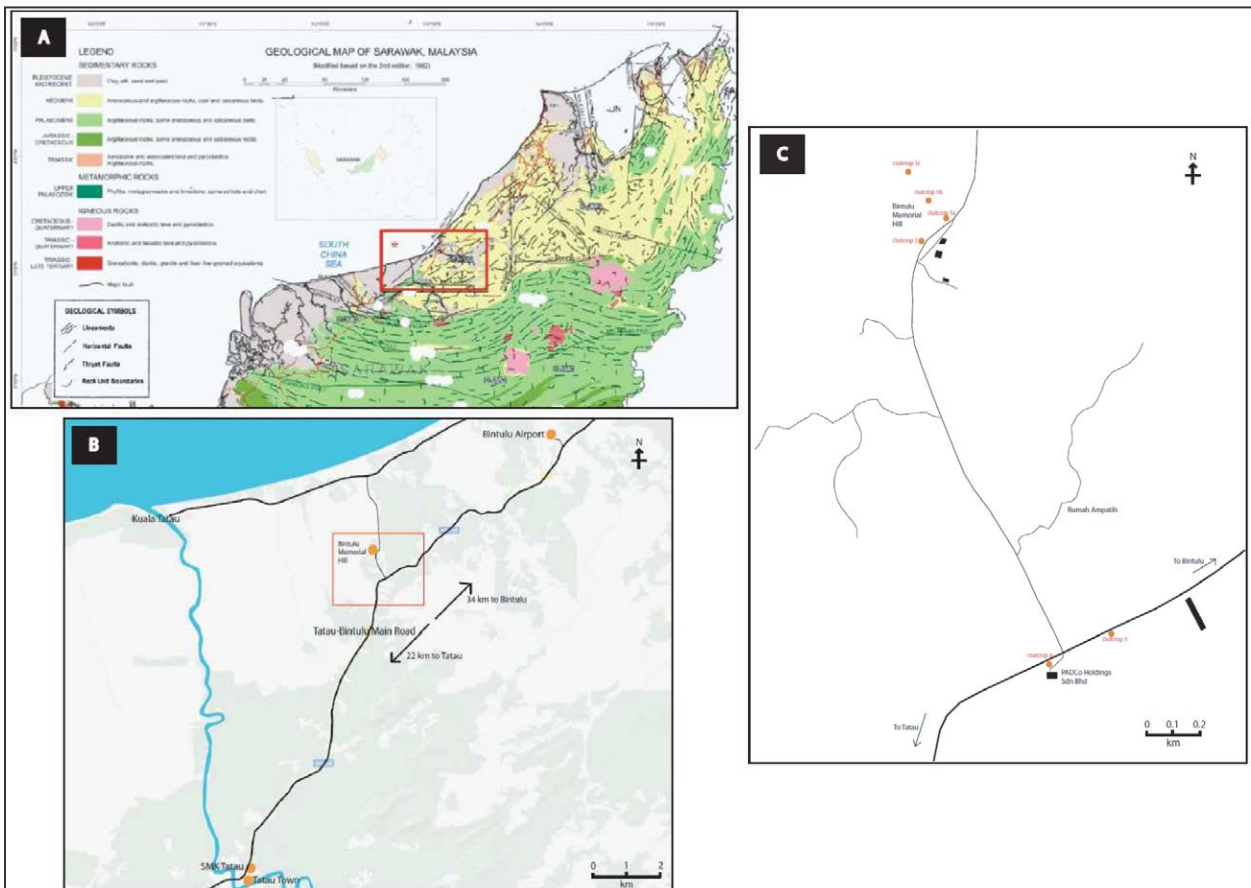


Figure 1: A – Geological and structural map of Sarawak; B – Location map of study area; C – Location of outcrops (1a, 1b, 1c, 2, 3 and 4).

Deposition and deformation of Sarawak young from west to east and south to north. The central part of Sarawak (Miri Zone) is deposited by several rock units, the oldest Lupar Formation, followed by Belaga Formations, Tatau, Buan and Nyalau Formations. Due to the lack of precise age indicators, the stratigraphical relationships between the formations have not been abundantly justified.

The extensive outcrops along in the vicinity of Tatau exhibit a variety of complex structures (Tjia *et al.*, 1987). According to Tjia *et al.* (1987), the lithology and tectonic deformation of the Early Tertiary sediments in Tatau area was interpreted to have occurred in a for-arc basin on the ocean side of a magmatic arc. Based on the stratigraphy of Miri Zone, the study area is believed to be closely related to Tatau Formation and Buan Formation. Tatau and Buan Formations are younger formations that surround the oldest formation in Tatau area, Belaga Formation. Both the formations were deposited under shallow marine to non-marine conditions.

The Tatau Formation (Upper Eocene to Oligocene) is made up of moderately to strongly folded rock units, probably uncomformable on Belaga Formation. It consists of medium to fine-grained sandstones and shale with intervals of marls and limestone lenses (Wolfenden, 1960). There are as well presence of argillite and slate. The formation was deposited in littoral to neritic environment. It composed of coarsening upwards heterolithic beds.

Evidence from previous studies indicated the presence of fossils in the Tatau Formation (Wolfenden, 1960). In

the Tatau Formation, limestone contains a rich fauna of Foraminifera. The limestone containing Foraminifera is Eocene and Oligocene in age. There are as well presence of rare gastropods, corals, echinoids fragments and calcareous green and red algae in the limestone. Marls of the same age of the Tatau Formation contain pelagic Foraminifera.

METHODOLOGY

A total of four outcrops (Figure 2) were studied where two outcrops are at Bintulu Memorial Hill and the other two along the Tatau-Bintulu main road (at the right from Tatau). Six exposed localities were logged with emphasis on: (i) lithology, (ii) bed thickness, (iii) bed contact, (iv) sedimentary structures, (v) fossil content and (vi) bioturbation style. Figure 3 shows the sedimentary log for Outcrop 3 which is located along the Tatau-Bintulu main road. Records were produced in three common forms: field notes, drawings and photographs and graphic logs. Further laboratory work such as petrography analysis were carried out with samples collected from the field.

RESULTS AND INTERPRETATION

Seven sedimentary facies which can be categorized into sand-dominated facies or mixed sand and mud-dominated facies have been recognized. Types of facies include:

- F1 - Massive sandstone
- F2 - Laminated sandstone



Figure 2: A total of four outcrops were studied. (a) Outcrop 1a with a total thickness of 3.25 m. (b) Outcrop 2 with a total thickness of 3.75 m. (c) Outcrop 3 with a total thickness of 15.5 m. (d) Outcrop 4 with a total thickness of 3.96 m.

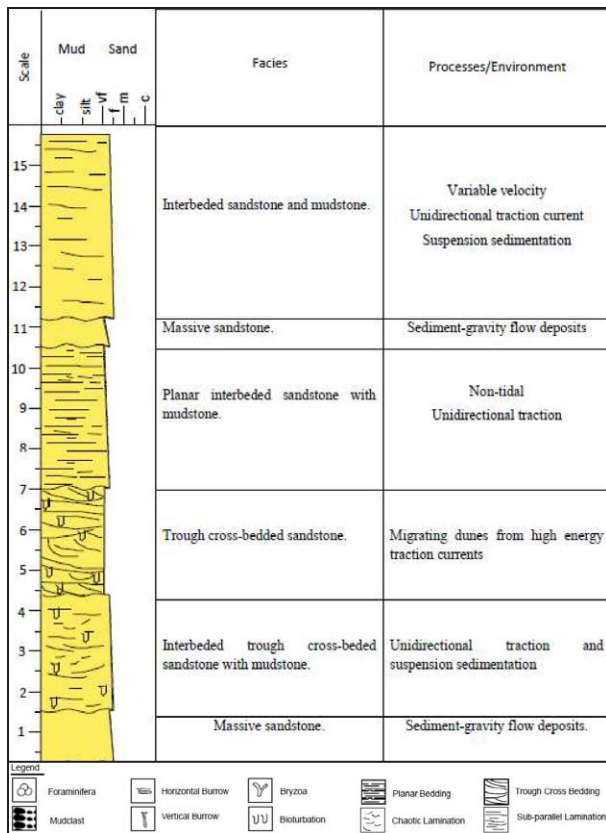


Figure 3: Sedimentary log for Outcrop 3.

- F3 - Amalgamated sandstone
- F4 - Trough cross-bedded sandstone
- F5 - Interbedded siltstone/mudstone and sandstone
- F6 - Heterolithic mudstone/siltstone
- F7 - Heterolithic sandstone

1) F1: Massive sandstone

Lithology and geometry

This facies is present in all the outcrops in the study area. It is light grey in colour, with good to moderate sorting and normal grading in grain size. The grain sizes of massive sandstone in all the outcrops are mainly very fine to fine/medium. Some of the F1 beds appear to be very thin like 0.01 m but the thickest F1 beds can be 3 m. Although most of the massive sandstones are soft, few beds are hard and less weathered. The facies has locally erosive or irregular upper and basal contact. It is often overlain by lamination or interbeds of siltstone or mudstone. F1 shows good lateral continuity across the whole outcrop.

Sedimentary structures

The massive sandstone beds are often structureless or may sometimes be internally graded upward into thin laminated sandstone with faint horizontal stratifications. There are existence of granules and intra-clasts such as mudclasts (Figure 4a). The mudclasts are usually moderately well-rounded and spherical; develop at the

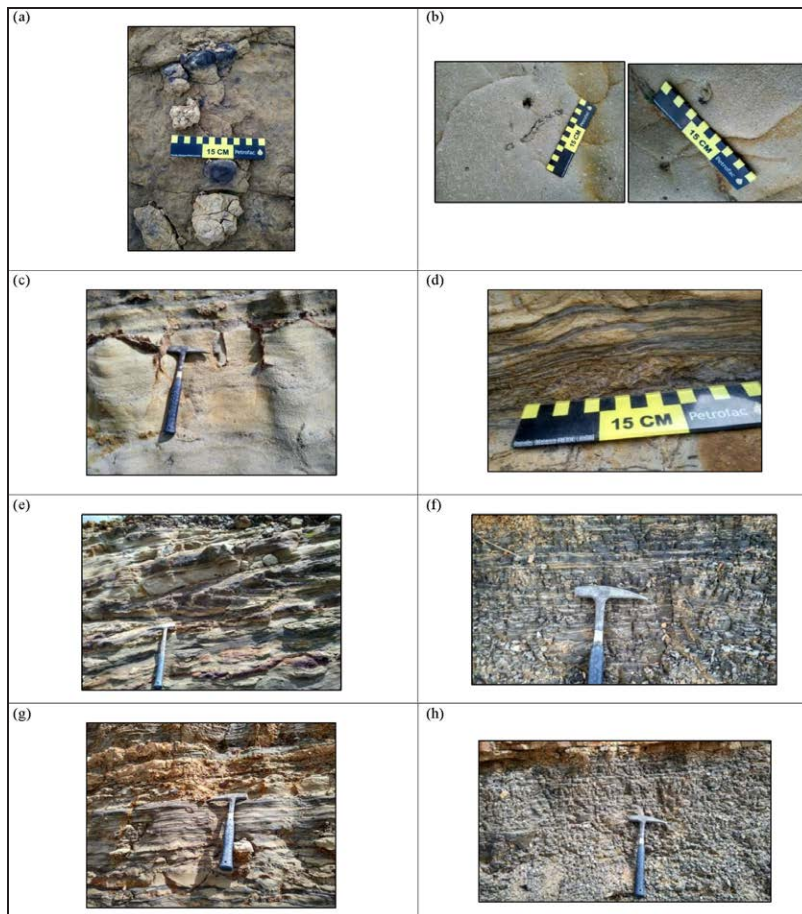


Figure 4: Main characteristics of facies.

- (a) Mudclasts (moderately well rounded and spherical).
- (b) Trails and tracks.
- (c) Laminated sandstone.
- (d) Skolithos (?) trace fossils and traces of plants.
- (e) Trough crossbedded sandstone.
- (f) Interbedded siltstone/mudstone and sandstone (lenticular).
- (g) Irregular and wavy stratification.
- (h) Heterolithic siltstone/mudstone.

bottom or towards the upper part of the beds. The thicker F1 beds can be of the same grain size, coarsening upwards or fining upwards. In the section with finer grains, structure such as climbing ripple lamination can be observed. Flame structure can as well be identified at the base of some beds due to the loading of this F1 facies on the top of weaker mud, compressing it.

Fossils content

Bioturbation is rare in this facies except for Outcrop 1(b) and Outcrop 2 with a moderate bioturbation index of 3 and 4. Most of the fossils found are trace fossils such as burrows, trails and tracks (Figure 4b).

2) F2: Laminated sandstone

Lithology and geometry

F2 is a common facies in the outcrops within the study area. It is light grey and grey in colour, with good to moderate grain size sorting. The grain sizes of laminated sandstone are mainly very fine to fine with silty or clayey lamination. Laminated sandstone beds (Figure 4c) range from 0.1 m to 0.5 m in thickness. The laminations of silt/mud are often thin with different configuration patterns for different beds including parallel, sub-parallel, irregular, chaotic and hummocky patterns. The beds have locally erosive or irregular upper and basal contact. The lateral continuity of the lamination within the sandstone varies.

Sedimentary structures

The main sedimentary structure in the F2 is the internal lamination siltstone/mudstone within sandstone beds. The horizontal stratifications differ showing patterns such as chaotic lamination, parallel lamination, wavy lamination and irregular lamination. Some of the beds show structure like climbing ripple lamination. Some lamination appears to be laterally continuous whereas some are pinching out. Mudclasts which are moderately well-rounded and spherical can be found in F2.

Fossils content

There is minor bioturbation in some of the laminated sandstone beds (index: 1 or 2). Most of the fossils found are trace fossils such as burrows, Skolithos (?) trace fossils and some traces from plants (?) (Figure 4d).

3) F3: Amalgamated sandstone

Lithology and geometry

Amalgamated sandstone is found at two of the upper beds in Outcrop 1(b). This facies is light grey-coloured as well as moderately sorted and graded in grain size. The grain sizes of F3 in the outcrop ranges from very fine to medium. They have a coarsening upwards sequence. The average thickness of the beds is around 0.4 m. The facies has an irregular upper and basal contact. There is thin siltstone /mudstone lamination within the upper amalgamated bed.

Sedimentary structures

The amalgamated sandstone beds lack in sedimentary structures. However, mudclasts can be found within the

beds, often at the top part of the beds. Thin lamination of siltstone/mudstone can as well be observed. Presence of flame structure at the bottom of the bed may be resulted from the pressure of the overlying sandstone on the softer siltstone/mudstone.

Fossils content

Presence of fossils can hardly be observed from the beds. This facies has a minor bioturbation index of 1.

4) F4: Trough cross-bedded sandstone

Lithology and geometry

F4 can be found in Outcrop 2 and Outcrop 3. It is light grey to yellowish in colour, with good to moderate grain size sorting and grading. This facies has very fine grain sizes. The trough cross-bedded sandstone beds (Figure 4e) are lacking in lamination and stratification of other rock types. Outcrop 3 has a thin bed of F4 which is 0.1 m whereas Outcrop 2 has a thick bed of F4 which is 5 m. The beds have locally erosive or irregular upper and basal contact. F4 shows good lateral continuity across the outcrop.

Sedimentary structures

The main sedimentary structure in the F4 is trough cross stratification. The cross-bedding shows the deposition of sediments in different direction. Mudclasts can as well be found in F4.

Fossils content

F4 in Outcrop 2 has a minor bioturbation index of 2. Most of the fossils found are trace fossils such as burrows and some traces from plants.

5) F5: Interbedded siltstone/mudstone and sandstone (lenticular)

Lithology and geometry

F5 is common in the Outcrop 1(a), 1(b), 1(c) and Outcrop 2. The alternation of siltstone/mudstone and sandstone in F5 (Figure 4f) is light grey and grey in colour. The dominant rocky-type in the beds is siltstone or mudstone. Layers of very fine or fine-grained sandstone are deposited in between the silty or muddy facies. F5 has a thickness ranging from 0.03 m to 0.8 m. The thin sandy layers in between can be of a few centimeters. The beds have locally erosive or irregular upper and basal contact. The lateral continuity of the dominant siltstone/mudstone layers is good but the continuity of the sandy layers varies.

Sedimentary structures

F5 shows lenticular bedding where siltstone/mudstone is dominant in the beds. Most of the beds show planar or parallel stratification while some beds are irregular, wavy (Figure 4g) or sub-parallel. Flame structure can be observed when there is deposition of sand on top of the weaker silt/mud.

Fossils content

F5 is poorly to moderately bioturbated in some of the beds (index: 1 to 3). Most of the fossils found are trace fossils especially burrows.

6) F6: Heterolithic Siltstone/Mudstone

Lithology and geometry

F6 can be found in Outcrop 1(b) and Outcrop 2. Heterolithic siltstone/mudstone (Figure 4h) is the alternate deposition of siltstone/mudstone and sandstone but is mainly siltstone/mudstone dominated. It is light grey and grey in colour. The significant characteristic of heterolithic beds is that the each lamination of the sediments should be 1 mm or less in thickness. F6 has a thickness ranging from 0.1 m to 0.8 m. The beds have locally erosive or irregular upper and basal contact.

Sedimentary structures

F6 shows thin alternate stratification of siltstone/mudstone and sandstone where siltstone/mudstone is the dominant rocky-type within the beds. Most of the beds show planar/parallel stratification while some beds are irregular. Flame structure can be observed when there is deposition of sand on top of the weaker silt/mud.

Fossils content

Minor bioturbation is observed in F6 (index: 1) with rare observable fossils, probably due to weathering.

7) F7: Heterolithic Sandstone

Lithology and geometry

F8 is rare among the outcrops in the study area and can be found in Outcrop 1(b). Heterolithic sandstone is similar to F6 where the only difference is in terms of dominant rocky-type which is sandstone. It is light grey and grey in color. Each lamination of the sediments should be 1 mm or less in thickness. F6 has a thickness of 0.3 m. The beds have locally erosive or irregular upper and basal contact.

Sedimentary structures

F7 shows thin alternate stratification of sandstone and siltstone/mudstone where sandstone is the dominant rocky-type within the beds. The bed has parallel lamination. Flame structure can be observed when there is deposition of sand on top of the weaker silt/mud.

Fossils content

There are no observable fossils in F7 and no significant bioturbation.

DISCUSSION

Table 1 is the facies scheme of the study area. Observations from six measured sedimentary logs suggest that the study area consists of six facies associations (FA): (1) fluvial/channel facies, (2) middle estuarine facies, (3) subtidal to intertidal facies, (4) prodelta facies, and (5) storm deposits.

The cross-bedded sandstone facies is formed as migrating dunes from high energy unidirectional traction currents in fluvial channel sand bars. The unidirectional dipping or planar lamination suggests unidirectional and uniform currents. The relationship of this facies with it under or overlying facies such as the heterolithic sandstone or mudstone (finer facies) and erosive basal contacts support this interpretation. There is a lack of trace or body fossils in within this facies in the study area, suggesting the deposition of the facies in a freshwater environment.

The interbedded sandstone and mudstone/siltstone facies is formed from variable velocity, unidirectional traction current and suspension sedimentation. There is a relative constant flow direction and a constant sediment supply, with the absence of tidal indicators. This facies of mudstone/siltstone and sandstone is deposited in prodelta and delta front settings, respectively.

The heterolithic mudstone facies is interpreted as deposits from alternating flood-ebb tidal currents and intervening slackwater suspension fallout in the lower tidal flat or subtidal coastline settings. Mud couplets or drapes, lamination bundles and thickness variations are some of the criteria that infer the occurrence of tidal process. The process may also be associated with sigmoidal cross-stratification in the facies.

The heterolithic sandstone is deposited in upper tidal flat, tidal channel or upper subtidal coastline settings which

Table 1: Facies scheme of the study area.

Lithofacies	Process	Environment
Laminated sandstone	Upper flow regime plan bed migration (varying energy).	Middle estuarine tidal
Laminated mudstone to siltstone/VF sandstone	Suspension fallout (low energy).	Restricted estuarine basin or embayment, restricted offshore transition
Cross-bedded sandstone, fine-grained sandstone	High energy, unidirectional traction sedimentation.	Fluvial channel sand bar
Interbedded sandstone and mudstone/siltstone	Unidirectional traction and suspension sedimentation (varying energy).	Non-tidal prodelta, delta front
Heterolithic mudstone	Lower energy tidal currents and slackwater fallout.	Lower tidal flat or subtidal coastline
Heterolithic sandstone	High energy tidal current and slackwater fallout.	Upper tidal flat, channel or coastline (subtidal-intertidal)
Bioturbated sandstone	Transgressive biologic and storm current sediment reworking.	Transgressive lag, storm deposits

is a subtidal to intertidal environment. The deposition is due to high energy tidal current and intervening slackwater fallout. Several exclusive features which can be observed are mud couplets/drapes with flaser or lenticular laminae and reactivation surfaces (indicating fluctuating flow velocities).

Last but not least, the bioturbated sandstone facies found in some sandstone beds is interpreted as transgressive lag or storm deposit. There is a high energy current deposition due to marine flooding or storm currents that was subsequently bioturbated. Comparison with the under or overlying facies such as heterolithic sandstone/mudstone or interbedded sandstone/mudstone supports the interpretation. The facies is overlain by finer grained facies. This suggests a period of higher energy current deposition due to marine flooding or storm reworking.

The Tatau Formation is characterized by sand-dominated facies as well as mixed-sand and mud-dominated facies. The facies strata are interpreted as estuarine, tidal flat, fluvial deposition and up to inner shelf strata. The laboratory analyses which suggest the presence of arenites signify the erosion of rocks or turbiditic re-deposition of sand which is probably originated from higher and inner ground. The deposition of arenites is then associated with deposition of lutite which is finer-grained sediments such as siltstone and mudstone which its source may come from inner ground or further erosion of sediments during transportation. There is a change and fluctuation in energy within the depositional environment due to frequent facies change and their structures.

Besides, the presence of trace fossils in the study area suggests that during the period of deposition, there was adequate and sufficient accommodation space and food supply within the environment of deposition until the deposition phase ends. The living organisms were able to accommodate themselves for a certain period of them with sufficient nutrient supply. Therefore, the evident supports the deduction of an estuarine-inner shelf region which belongs to the shallow marine environment.

CONCLUSION

The Tatau-Bintulu area has been categorized as part of the Miri Zone of Sarawak Basin. For early Neogene formations of the study area, focus of this study is on the sedimentary formations that overlie the Belaga Formation (Paleogene). Tatau Formation is geologically and stratigraphically related to the study area.

The Tatau Formation consists mainly of carbonaceous shale and siltstone, with some beds of sandstone. Although there is no observable unconformity, photogeological and field evidence suggested that the Tatau Formation lies unconformably on the Belaga Formation.

From the field study as well as laboratory analysis, the outcrops in the study area do show similar facies and characteristics as the Tatau Formation. The common rock types present are sandstone, mudstone and some rare shale. Seven types of facies which can be categorized into sand-dominated facies or mixed sand and mud-dominated facies were identified. Fluctuation in depositional energy resulted in alternation of sediments and their structures from finer to coarser sediment and planar to erosive surfaces. The rise and drop in sea level influence the energy during the deposition phase as well as sequence of deposition (fining-upward or coarsening-upward sequence). Besides, the available accommodation space influences the thickness of the sediments deposited from thinner beds to thicker beds. The facies associations in the study area propose an estuarine-inner shelf environment, showing rare transgressive characteristics.

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