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Stratigraphic Succession and Depositional Framework of the Sandakan Formation, Sabah

(Penyesaran Stratigrafi dan Rangka Bentuk Pemendapan Formasi Sandakan, Sabah)

KHOR WEI CHUNG*, CHOW WENG SUM & ABD. HADI A. RAHMAN

ABSTRACT

The Sandakan Formation of the Segama Group is exposed across the Sandakan Peninsular in eastern Sabah. This Upper Miocene part of the Segama Group unconformably overlies the Garinono Formation and is conformably overlain by the Bongaya Formation. This formation was investigated with detailed logging of outcrops and microfossils analysis in order to map the depositional facies and sedimentary environment. This study showed the presence of seven lithofacies: Thick amalgamated sandstone; thin, lenticular interbedded HCS sandstones and mudstone; laminated mudstone with Rhizophora*; trough cross-bedded sandstone; laminated mudstone; strip mudstone with thin sandstone and siltstone; and interbedded HCS sandstone and mudstone. Based on the presence of* Rhizophora, Brownlowia, Florchuetia *sp.,* Polypodium, Stenochleana palustris, Ascidian spicule *low angle cross bedding, very fine grained sandstone, thin alternations of very fine sandstone, silt and clay layers showing cyclicity (muddy rhythemites), rocks in the Sandakan Formation are interpreted as mangal estuary and open marine facies. Three facies associations could be deduced from the seven lithofacies: Gradual coarsening upwards shoreface; abrupt change facies and prograding estuary facies association.*

Keywords: Facies; facies description; micropaleontology; Sandakan formation; sedimentology; stratigraphy

ABSTRAK

Formasi Sandakan adalah sebahagian daripada kumpulan Segama terbentang di seluruh Semenanjung Sandakan yang terletak di timur Sabah. Miosen Akhir ini ialah sebahagian daripada kumpulan Segama yang tidak menyama bentuk Formasi Garinono dan menyama bentuk oleh Formasi Bongaya. Formasi ini telah dikaji dengan pengelogan terperinci pada singkapan dan juga analisis mikrofosil untuk memetakan pemendapan fasies dan sedimen persekitaran. Kajian ini telah menunjukkan kehadiran lapan litofasies: Batu pasir tebal bersatu; batu pasir dan batu lumpur HCS berlapis benam kekantaan nipis; batu lumpur berlamina dengan Rhizophora*; batu pasir dengan serpihan cengkerang; batu lumpur berlamina; batu lumpur berjalur dengan batu pasir dan batu lodak nipis; dan batu pasir dan batu lumpur HCS berlapis benam. Berdasarkan kehadiran* Rhizophora, Brownlowia, Florchuetia *sp.,* Polypodium, Stenochleana palustris, Ascidian spicule *sudut rendah perlapisan silang dan juga butiran saiz pasir yang halus pada Formasi Sandakan ditafsirkan sebagai muara mungal dan fasies marin terbuka. Tiga perhubungan fasies boleh disimpulkan daripada tujuh litofasies: pengasaran secara beransur-ansur ke atas permukaan laut; perubahan mendadak fasies dan fasies perhubungan muara.*

Kata kunci: Fasies; butiran fasies; Formasi Sandakan; mikropaleontologi; sedimentologi; stratigrafi

INTRODUCTION

The Sandakan Formation is located in the Sandakan Peninsular in East Sabah. It is exposed in the Eastern Sabah from Sungai Garinono until Pulau Berhala (Figure 1). This research focuses on evaluating the depositional environment of the Miocene - Sandakan Formation in East Sabah. Previous studies by Fitch (1958), Haile and Wong (1965) and Staufer and Lee (1972) have described the Sandakan Formation and concluded that this formation consists of three fundamental facies, namely mudstone, sandstone and conglomerate facies. Noad (1998) proposed that the Sandakan Formation is deposited in a shallow marine and mangal environment, while Tulot (2002) proposed a shoreface environment. Ahmed Tarek (2002), evaluated the geochemical elements and facies of this formation.

The research area covers approximately 12 km^2 from longitude E118˚ 02.553' to E118˚ 07.993' and latitude N05 050.095 to N05˚ 51.286'.

The Sandakan Formation as observed from the outcrops overlies the volcaniclastic sediments of the Lower - Mid Miocene Garinono formation (Figure 2) with shallow regional unconformity (SRU) as the contact (Tulot 2002). The shallow regional unconformity has been dated to be Middle – Late Miocene, Tf_{1-2} (Lee 1970). This project involves fieldwork to acquire data on microfossils, biofacies, sedimentology and stratigraphic succession.

The main goal of this research was to integrate micropaleontological and sedimentological data to reconstruct the paleoenvironment evolution of the Sandakan Formation during the mid to late Miocene within a sequence-stratigraphic framework.

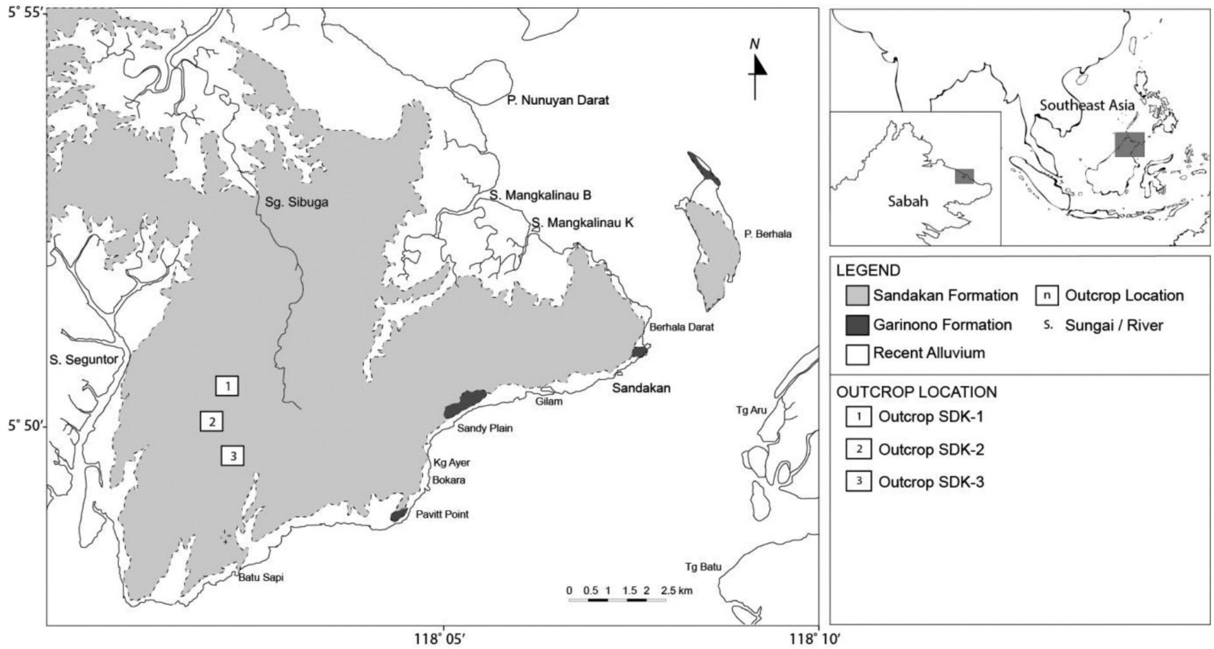


FIGURE 1. Sabah Regional Geological Map and locality of outcrops studied across Sandakan Peninsular. (Modified from the Geological Map of Sandakan Peninsula, Geoscience and Mineralogy Department of Malaysia

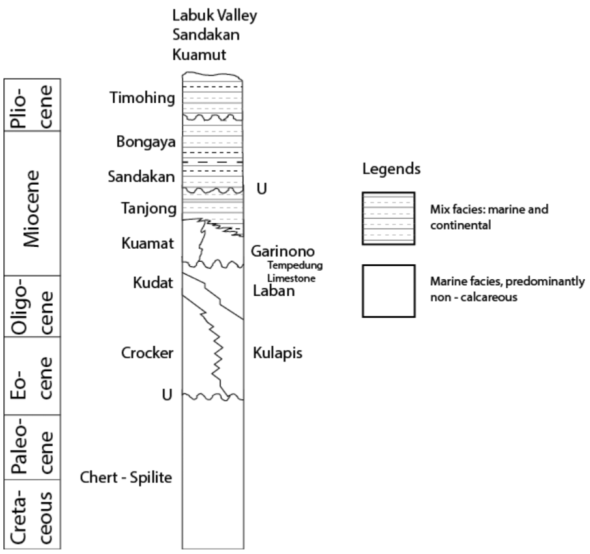


FIGURE 2. Generalized stratigraphy of the Labuk Bay, Sandakan and Kuamat (modified after Leong in PETRONAS 1999)

The specific objectives of the study were to describe and interpret the sedimentary facies of the Sandakan Formation; to identify the facies associations in terms of sedimentary processes and environments; to determine the microfossil assemblages and their paleoenvironmental implications; and to propose a depositional model taking into account of the sedimentological and micropaleontological characteristics of the Sandakan Formation and their evolution through time within a sequence-stratigraphic framework.

GEOLOGICAL SETTING

The geology of the Sabah region can be divided into five major tectonic stages from Cretaceous to Pliocene (Tongkul 1992). The tectonic history of East Sabah, including the Sandakan Peninsular started during the second stage which ranged from Oligocene to Early Miocene. The northeast trending Sandakan rift and the southeast trending Tarakan rift took place after the formation of Rajang Group Fold Thrust Belt (RFTB) during Eocene (PETRONAS 1999). These events resulted in the opening of Sandakan and Tarakan Basins (Leong 1976). Sandakan Basin underwent another tectonic event at the northwest direction.

The third stage of this deformation took place from early Miocene to middle Miocene. At the east of Sandakan Basin, the Sulu Sea opened, resulted in the widening of the Sandakan Basin which serves as a new and larger depocenter (Hutchinson 1997).

In late Miocene to early Pliocene, the rifting stopped and caused a major uplift around the Sandakan Peninsula (Tongkul 1992). These uplifts came along with heavy erosion as it could be seen as the Shallow Regional Unconformity (SRU). SRU marks the inflection point between two major regional subsidence in early Miocene, which took place on the western side. The two major regional subsidence on the NW Sabah are: Rapid tectonic subsidence (>500 m/Ma) between 14.7 and 9 Ma followed by a generally slow subsidence. SRU stretches all along from the east of Baram Delta, east of Sarawak to the Tarakan Basin, southeast of Sabah (PETRONAS 1999).

There is no complex deformation in the Sandakan Formation other than tilting due to uneven uplift. The Sandakan Formation is gently dipping in the southwest direction (Tulot 2002). The Sandakan Formation is gently dipping in the northwest direction.

FACIES DESCRIPTION

This paper discusses three outcrops in the south of Sandakan Peninsula. The locations of the outcrops are shown in Figure 3. The stratigraphic sections of the logged outcrops are shown in Figure 3, 5 and 6.

F1: THICK AMALGAMATED HCS/SCS SANDSTONE

Sedimentological description This facies comprises of light brown, fine to very fine grained sandstone. These amalgamated sandstones are well sorted. Based on the thin section analysis, the sandstone has approximately 25% of porosity. The grains are also sub-rounded and sub-angular. Individual sandstone beds generally pinch out, but the bedsets are laterally persistent. The sandstone beds are stacked (amalgamated) especially at the channel structures. The sandstone units can be 10 cm to 11 meters in thickness, but commonly 15 cm to 4 meters thick. Load cast, mud balls and thin lenticular mud structures could be seen near to the base of the sandstone units. Sandstone beds that are thicker than 2 m show Swaley Cross Stratification (SCS).

Biofacies Trace fossils are very rare though oblique burrows may occur. Bivalve and gastropod casts are rarely seen.

Interpretation Thick amalgamated beds displaying hummocky cross-stratification represents proximal storm beds and record high-energy oscillatory and combined flows during storms (Buatois & Mangano 2003). This thick bedded, amalgamated hummocky sandstone were formed by repeated storm events. Wave erosion removed mud layers between sandstone beds. This facies took place

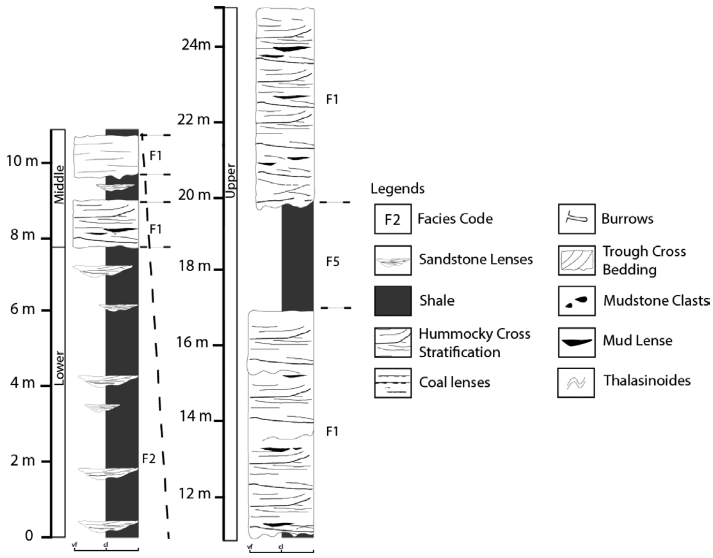


FIGURE 3. Stratigraphic column of Outcrop SDK-1

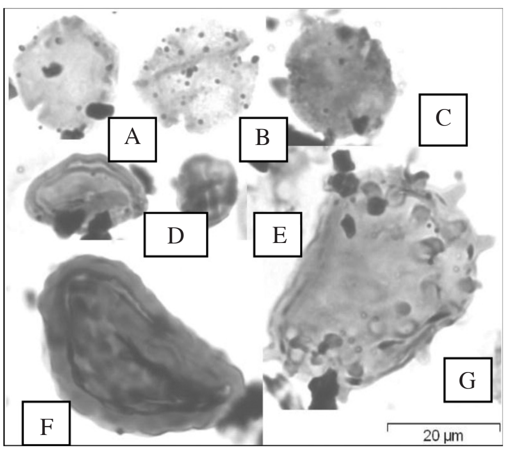


FIGURE 4. Spores and pollens found in Outcrop SDK-2. A, B & C) *Brownlowia* , D) *Florschuetzia* sp. E) *Rhizophora*, F) *Polypodium* G) *Stenochleana palustris*

higher than fair eeather wave base (FWWB) where it is affected by the periodical storm event current (Tulot 2002). The high energy storm current is strongly erosive and is able to remove the top mud layers before the sandstone grains settle down. The deep scours indicate strong erosive flows whereas large load cast suggest rapid influx of sand (Selly 2000). Amalgamated fine to very fine grained sandstones are typical of the lower middle shoreface and have been reported in the literature (Buatois & Mangano 2003; Tulot 2002).

F2: THIN INTERBEDDED HCS AND MUDSTONE

Sedimentological description Facies 2 is mudstone dominated with regularly interbedded thin sandstone. The sandstone units occur from 5 - 40 cm in lenticular structure. The sandstone units are not laterally extensive. It is brownish with erosive-based, fine to very fine grained sandstone and some units contain hummocky cross stratification (HCS).

Biofacies Micropaleontologic analysis at the mudstone samples shows sparse distribution of pollen, foraminifera and nannofossil. A landwards direction pollens, *Rhizophora* and *Shorea* could be found but are uncommon in this facies. Similarly the nannofossils, *Sphenulitus abies and Reticulofenestra spp.,* could be rarely found in this facies.

Interpretation The thin lenticular sandstones are the drains that scour through the mudstone (Pettijohn et al. 1972). The depauperating distribution of pollen and nannofossils may suggest that they are transported from adjacent environment. Both *Rhizophora* and *Shorea* could be dominantly found in a fluvio-estuary environment (Jenkins 1993). The small counts could explain that the pollens had been transported down from the terrestrial direction. This facies is interpreted to have been deposited at the upper offshore environment.

F3: LAMINATED MUDSTONE WITH *RHIZOPHORA*

Sedimentological description Approximately 17 m of the exposed at locality 3, Outcrop SDK-2 (Figure 5). This facies is grey to dark grey in color with large amount of mud, abundant lignite and amber. Occasionally, accumulation of thin coal lenses, leaves cast and petrified wood could be found. Thin-shelled bivalve fragments are rare within the mudstone.

Biofacies Thalassinoides are present in the mudstone beds. These bivalve fragments are present in all the beds and are occasionally associated with petrified wood. *Rhizophora* pollen type is abundant in this facies. Other types of pollens found such as *Stenochleana palustris* and *Shorea* are rarely found (Figure 4).

Interpretation This facies is interpreted as the deposits of low energy, estuary environment with tidal influence. The thick mudstone deposits, rich with well-preserved pieces of trunks and leaves cast, suggest that these beds were deposited in a reducing/ anoxic condition (Noad 1998; Tulot 2002). The absence of burrows in this facies suggests that either the rate of sedimentation was too rapid or the salinity was too low to support burrowing organisms (Buatois & Mangano 2003). The dominance of *Rhizophora* pollens, depauperate distribution of foraminifera and nannofossils and abundant lignite/coal suggest that the area was formerly a low coastal plain (see previous interpretation), with a low tide dominated and low energy depositional environment. It is also highly affected by tide.

The presence of nannofossils, *Sphenolitus abies* ranges from Late-Miocene (NN11), to Early-Pliocene (NN15), along with *Coronocyclus nitescens* that ranges from Early-Miocene (NN2), – Late Miocene (NN11). *Reticulofenestra* sp is also found in the samples. These nannofossils are present in marine environment

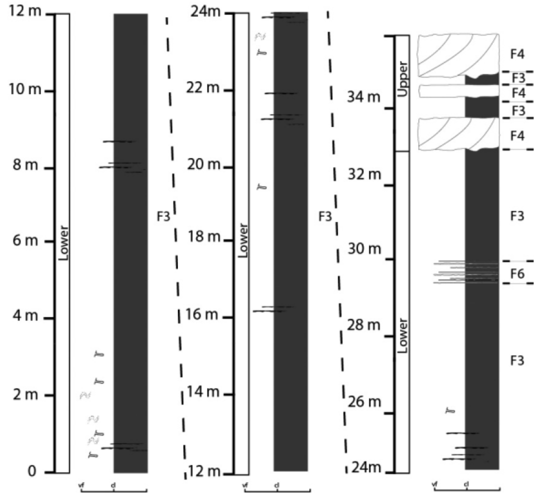


FIGURE 5. Stratigraphic column of Outcrop SDK-2

FIGURE 6. Picture of Outcrop 3C, featuring Shallow Water Interbedded Facies and Sandstone with Scouring Contact

(Hutchinson 2005; Lee et al. 2004). This supports that Sandakan Formation is deposited during Late Miocene.

F4: TROUGH CROSS-BEDDED SANDSTONE

Sedimentological description These facies consist of light brown and medium to fine grained sandstone. The beds range from 70 to 100 cm in thickness. The trough cross bedding is in a preferred orientation, particularly dipping in southeast direction. The sandstone beds compose of isolated mudstone lenses and mudballs. The mudstone lenses are averagely 6 cm in length and 1 cm in thickness. Fining and thinning upward in the sandstone are common. Based on the thin section, the sandstone grains are well sorted to moderately sorted with few fractured grains and minor intra-grains cementation. Apparently, the estimated porosity is approximately 11%. The grains are also subangular and subrounded. It is also categorized as arenite for more than 95% of quartz grains.

Fossils The distribution of fossils in this facies is very uneven. The brachiopods and gastropods appear to be fractured and have thin shells. Occasionally, the casts of these fossils are present.

Biofacies Facies 4 is present in the Outcrop SDK-2 and is associated with Facies 3, thick mudstone with abundant *Rhizophora*.

Interpretation Tidal currents are considered the depositional mechanism of facies 4. The presence of mud lenses, mud balls and erosional base indicates erosion and sands deposition from tidal currents (Reading 1996). The mud deposited during slack-water intervals and eroded away during the sand deposition. This facies is most likely to form in upper subtidal to intertidal flat environments (Selly 2000). The upward decrease in grain size and vertical changes in bedforms suggest a decrease in flow velocity and sand supply (Buatois & Mangano 2003). This could also be linked to flat tidal shallowing.

F5: LAMINATED MUDSTONE

Sedimentological description This facies comprises of black grey mudstone. The mudstone unit displays sharp top contact. The mudstone consists of subangular to angular claystone, pyrite and quart.

Ichnology Bioturbation is absent.

Interpretation Facies 5 records low energy, suspension fallout deposition in the absence of waves and currents (Buatois & Mangano 2003). The absence of bioturbation, dark colour and massive structure suggest an oxygen-depleted conditions (Potter et al. 2005). The absence of oscillatory structures indicates that the deposition occurs below storm wave base. Facies 5 is interpreted to be deposited in a shelf environment. The mudstone laminaes are commonly silt rich. This facies is present at Outcrop SDK-2.

F6: STRIP MUDSTONE WITH THIN LAMINATED SANDSTONE AND SILTSTONE

Sedimentological description This facies contains thinly laminated greyish mudstone and sandstone. The sandstones are fine to very fine grained and appears to be brownish - orange in colour. This facies ranges around 2 cm in thickness. This facies can be divided into two subfacies which are: parallel laminated sandstone and mudstone; and ripple laminated sandstone and mudstone. Mud drapes are common within the wrinkles (ripple cross - lamination).

Ichnology Trace fossils are relatively rare in this facies. Occasionally, vertical burrows are found cutting through the laminaes.

Interpretation The alternating laminated sandstone and mudstone and the muddrapes suggest a tidal influenced environment (Yoshida et al. 2004). The variations of tidal currents can be indicated through the thinning and thickening trends (Kvale & Archer 1990; Kvale et al. 1989). Based on Buatois and Mangano (2003), this facies can be interpreted as tidal rhythmite. This facies indicates a low energy intertidal flat depositional setting.

F7: INTERBEDDED HCS SANDSTONE AND MUDSTONE

Sedimentological description This facies comprises of laterally extensive units. Hummocky Cross Stratification,

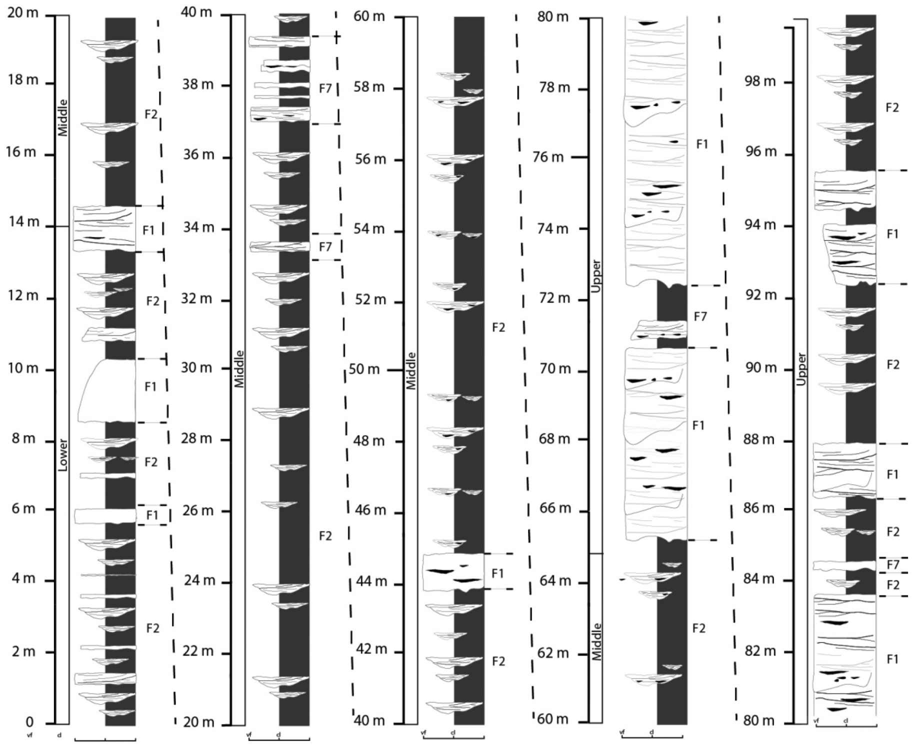


FIGURE 7. Stratigraphic column of Outcrop SDK-3

fine to very fine grained, well sorted to moderately well sorted and scouring basal contact are present in the sandstone beds. The sandstone units are 10-140 cm in thickness, commonly 40 - 70 cm, while the mudstone units are approximately 60 cm thick. The sandstones are also grains supported with point contacts and comprise more than 95% of quartz and quartz arenites. The shape of the grains is subangular and subrounded. Occasionally, coal trunk could be found in the sandstone beds.

Ichonology Bioturbation is rare.

Biofacies Micropaleontological studies show barren result in foraminifera, spores, pollens and nannofossils.

Interpretation This facies suggest an offshore transition environment. It represents a quiet-water sediment fall-out and repetitively. The various thickness of beds suggest that it formed at a moderately strong, intermediate cycles of flow (Pettijohn et al. 1972). Offshore transition deposits are commonly explained by a regular alternation of sandstones and mudstones (Buatois & Mangano 2003).

FACIES ASSOCIATION

FACIES ASSOCIATION 1 (FA 1)

FA1 comprises a lower mud-dominated interval, bearing nannofossils are planktic microfossils (*Sphenulitus abies*), intermediate interval of thin HCS beds and capped by a thick (4-5 m) SCS unit. Facies association 1 shows upward coarsening from mud - dominated to sandstone dominated sediments interval (Facies 1, F1 and Facies 2, F2). The thickness of Facies 1 (F1) varies from 1 to 5 m while F2 varies from 0.5 to 6 m. F1 contains amalgamate sandstone with faint low angle hummocky cross stratification lamination while F2 contains mudstone with thin HCS sandstone lenses.

The mudstone with thin laminated HCS sandstone lenses of the F2 reflects a proximal input of sediments. The mudstone is mainly formed by suspension, sediments, which is inferred to be null wave influence. The lenses, gutter casts, in the mudstone (which are commonly 30 cm in thickness and 3 meters in length) indicate the drainage and a high energy flow during the storm period. Thus, F2 is deposited in the offshore transition environment where it is located right below of the FWWB (Fair Weather Wave Base) and above SWB (Storm Wave Base).

This facies association 1 (FA 1) is a product of shallow marine deposition. This assemblage of thick amalgamated sandstone may correspond to the wave dominated environment - upper shoreface. This indicates that the sandstones were deposited above the FWWB.

The full series of an ideal prograding shoreface could not be seen, however, this section captured almost a complete lower distal transition zone to a proximal upper shoreface environment. The beds were deposited gradually in a shallowing upwards sequence - from an offshore transition environment into lower shoreface and upper shoreface.

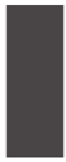
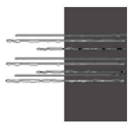
Facies Name / Code	Description	Stratigraphic section	Location (Outcrop)
F1 Thick Amalgamated Sandstone (Lower Middle Shoreface)	• Faint HCS • Fine to very fine grained • Erosive scouring basal contact • Irregular to flat top contact • Mudstone clasts and lenses are present		SDK-1 SDK-3
F2 Thin , Lenticular Interbedded HCS Sandstones and Mudstone (Upper Offshore)	• Sandstone appears as lenses • The thin HCS sandstones are fine – very fine grained • Lenses with erosive base • Mudstone dominated • Low micropaleontological recovery • Micropaleontology: *palustris, Brownlowia, Stenochleana palustris, Ammobaculites, Sphenulitus abies, Reticulofenestra* spp, *Coronocyclus nitescens*		SDK-1 SDK-3
F3 Laminated Mudstone with Rhizophora (Tide Dominated Estuary)	• Sharp top contact • Dark grey • Low bioturbation • Micropaleontology: *Rhizophora, Brownlowia, Shorea, Stenochleana laurifolia*		SDK-2
F4 Trough Cross-bedded Sandstone (Subtidal to Intertidal Flat)	• Cross bedding • 0.7 – 1 m in thickness • Commonly fining upwards • Medium – fine grained		SDK-2
F5 Laminated Mudstone (Shelf)	• Sharp top contact • Irregular basal contact • Low bioturbation rate • Very low micropaleontological recovery		SDK-1
F6 Strip Mudstone with Thin Laminated Sandstone and Siltstone (Low Energy Intertidal Flat)	• Beds approximately 1 cm or less than 1 cm in thickness • Sandstones are fine to very fine		SDK-2
F7 Interbedded HCS Sandstone and Mudstone (Offshore Transition)	• Averagely 30 cm in thickness • HCS and streaks • Sandstones fine to very finely graded • Sandstone has erosion basal contact • Low micropaleontological recovery • Micropaleontology: *Rhizophora, Brownlowia, Acrostichum aureum, Stenochleana palustris*		SDK-3

FIGURE 8. Summary of stratigraphic sections of Sandakan Formation

There are two possibilities that can be deduced from this succession: Where the sediment input was high but the sea level was rising gradually; or the sediment input was low but the sea level was constant (Holland 2008).

FACIES ASSOCIATION 2 (FA2)

Facies association 2, FA 2, comprised of thick amalgamated sandstone, F1 and laminated mudstone F5. The F5 contains nannofossils (*Sphenulithus abies)* which is a marker for a depositional environment shallower than 400 m depth. Other than the nannofossils, F5 is barren of other micropaleontological analysis, foraminifera and palynology. The 3 m thick mudstone is interpreted to have been deposited in a shelfal condition mainly in a low energy setting.

FA2 shows an abrupt change of lithology from F5 to F1 with a high relief scouring contact (commonly 30 cm). Such an abrupt change, from shelfal to the upper shoreface environment could be explained by the rapid fall of sea level. Usually heavy erosional surface like incised valley is associated with this event. However, where the environment is below the SWB, the rapid fall of sea level will produce an abrupt change of lithology. This occasion could be explained as a Forced Regression of a Falling Stage System Tract (FSST) (Plint & Nummedal 2000).

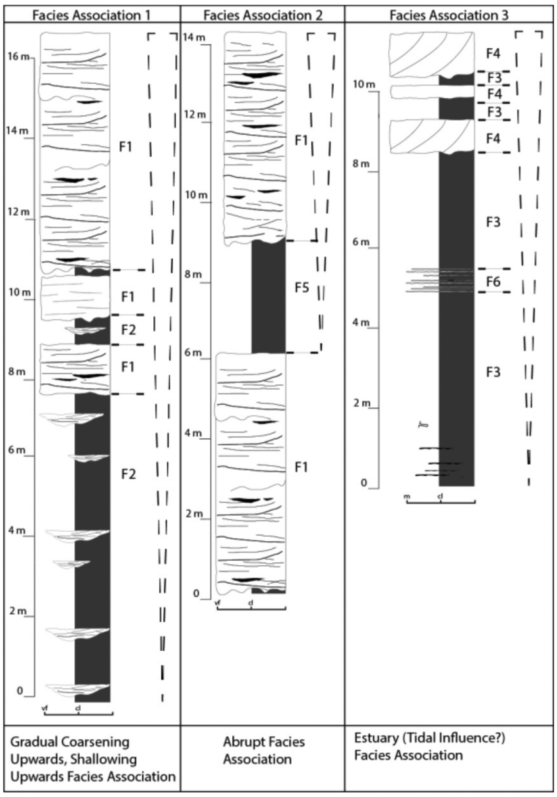


FIGURE 10. Facies associations from the research area of Sandakan Formation

FACIES ASSOCIATION 3 (FA3)

This facies is made up of lower F3 (laminated mudstone with *Rhizophora*, F6 (minor strip mudstone with thin laminated sandstone and siltstone) and F4 unit at the top (trough cross bedded sandstone). The thickness of F3 may individually exceed 10 m. F3 is dominated by organic rich carbonaceous mud. Some brackish environment foraminiferas, pollens and spores recorded were the *Ammobaculites, Rhizophora, Shorea* and *Brownlowia*. The F6 also contains minor thin alternation of mudstone and sandstone slivers (F6). This thin alternation may represents the episodic flooding event.

The upper section of FA3 is dominated by 1-2 m medium grained trough cross bedded sandstone. The abrupt change from a brackish mudflow to trough-cross bedded fluvial sandstone reflects a marked change in the flow regime. The top sandstone unit is interpreted to be fluvial in origin. The trough cross bedding also represents a unidirectional flow which may be due to the fluvial currents.

The change in this sequence signifies that the sea level retreat further seaward. This causes the deposition of fluvial related sandstone on the thick estuary mudstone.

DEPOSITIONAL ENVIRONMENT

Seven lithofacies, which have been defined, contain both muddy and sandy facies. The facies association indicates that the Sandakan Formation was once an open marine and estuarine environment in which the estuary directly met with the shoreface environment.

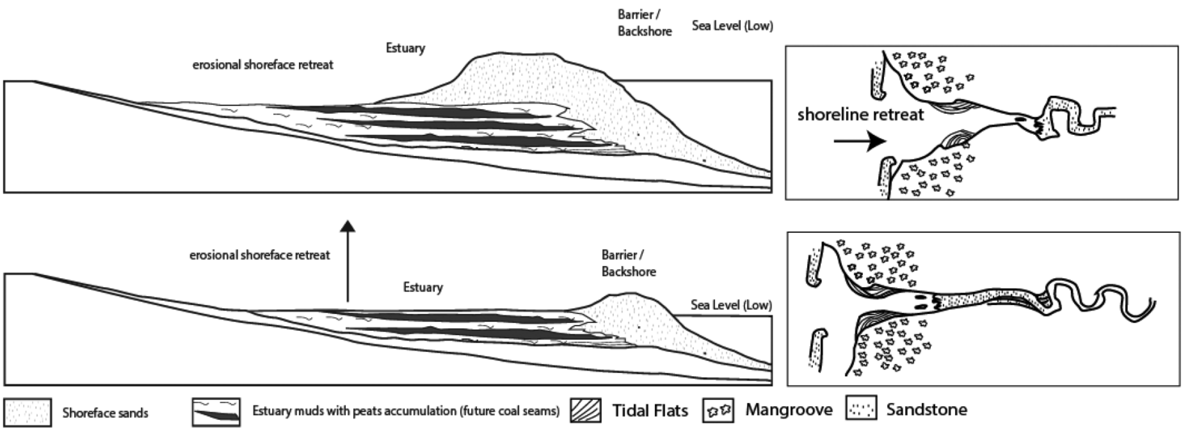


FIGURE 11. Stratigraphy evolution of Sandakan Formation from estuary environment to shoreface

The presence of lithofacies laminated mudstone with *Rhizophora* (F3), trough cross bedded sandstone (F4) and strip mudstone with thin sandstone and siltstone (F6) support the estuary model. The thick laminated mudstone with high carbonaceous materials may be deposited at a brackish environment particularly the mangrove swamp (mangal). The mangrove swamp is a buffer zone between the coastal area and the land. It also acts as a natural defense line against the storm currents. Thus, thin sand slivers, disarticulated mollusc, tree branches and trunks may dissipate over the mangal mudstone.

The open marine environment that overlay the estuary environment is explained by the presence of the thick amalgamated sandstone (F1), the thin, lenticular interbedded HCS sandstones and mudstone (F2), laminated mudstone (F5) and interbedded HCS sandstone and mustone (F7). In a typical shoreface environment, the succession is mud-dominant in the distal direction and wave related structures are significant as environment indicators (Buatois & Mangano 2003). The low angle HCS, scouring contacts, reliefs, rippled surface, thin stratified sandstone lenses and amalgamated sandstone with faint lamination are mainly found in the wave dominated condition.

CONCLUSION

The Sandakan Formation is represented by shallow marine and shoreface succession. The shoreface sandstone overlies the carbonaceous mudstone. Seven lithofacies were recorded from the Sandakan Formation. These are: thick amalgamate sandstone; thin, lenticular interbeded HCS sandstones and mudstone; laminated mudstone *Rhizophora*; trough cross-bedded sandstone; laminated mudstone; strip mudstone with thin laminated sandstone and siltstone; and interbedded HCS sandstone and mudstone. The lithofacies can be grouped into three environmental distinctive facies association. These are: gradual prograding open marine succession; the abrupt change open marine association; and the prograding estuary sequence. The overall stratigraphic organization of lithofacies and facies association reflects a change from estuarine to shallow upper shoreface setting with a background of relative sea level rise. The abundance of *Rhizophora* in the estuarine mudstone indicates a mangal depositional environment. The remnants of storm currents are also present.

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