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The Late Miocene Sandakan Formation, East Sabah: facies, depositional environments and relative sea level change

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This paper discusses sedimentary facies and lithofacies associations and their depositional environments with the relative sea level change.

The Sandakan Formation is situated within the Central Sabah sub-basin, which is located on the east coast of Sabah. Rock belonging to the Sandakan Formation can be found exposed in the Sandakan Peninsula and the Dent Peninsula, which lie between Labuk and Darvel Bays. The type area of the Sandakan Formation is the Sebuga area lying between the Batu Sapi Road on the south and the Labuk Road on the north.

Twelve sedimentary facies have been identified within the Sandakan Formation. These facies are: SDS1 (rippled tops sandstone), SDS2 (thick sandstone-shale interbedding), SDS3 (thin sandstone-shale interbedding), SDS4 (hummocky cross-stratified sandstone), SDS5 (channelized/gutter cast sandstone), SDS6 (thick clean, cross-bedded sandstone), SDS7 (sandstone lenses/layers), SDM1 (grey mudstone with carbonaceous materials, coal fragments), SDM2 (lenticular-bedded mudstone), SDM3 (laminated-mudstone), SDM4 (laminated-mudstones with interbedded laminated siltstone and sandstone), and SDC1 (coal layers).

These facies can be grouped into six different lithofacies associations, namely:

1) Lithofacies association A (thick laminated-mudstone with gutter cast)
2) Lithofacies association B (hummocky cross-stratified sandstone interbedded with facies SDM4)
3) Lithofacies association C (thick clean, cross-bedded sandstone)
4) Lithofacies association D (sandstone-shale succession)
5) Lithofacies association E (laminated-mudstone with coal clasts)
6) Lithofacies association F (laminated-mudstone with coal layers)

Lithofacies association A represents offshore, shelfal mudstone. Lithofacies association B interpreted as having been deposited within the lower shoreface zone. The upper shoreface environment is represented by lithofacies association C. Lithofacies association D represents tidal flat environment. The lagoonal-estuarine and -swamp environments are suggested by lithofacies associations E and F.

The proposed stratigraphic organization of the investigated Sandakan Formation, based on the geographic locations of the outcrops and the structural geology of the formation, shows that the thick laminated-mudstone with gutter casts sandstone of lithofacies association A represent the lowermost part of the investigated Sandakan Formation. This lithofacies association may be succeeded by thick hummocky cross-stratified sandstone of lithofacies association B. The tide-dominated, lagoonal-swamp and -estuarine of lithofacies associations F and E with tidal flat deposits of lithofacies association D in the Cecily Road and IOI-Kg Bahagia represent the middle parts of the succession. The uppermost part of the succession represented by the presence of upper shoreface of lithofacies association C.

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The stratigraphic organization and lithofacies associations of the Sandakan Formation suggest three contrasting paleoenvironmental settings: open-marine, tidal flat and lagoonal-estuarine and -swamp. The organization of lithofacies associations A, B, F, and E of the Sandakan Formation suggests a gradual, overall, upward-shallowing of environment and a marked change in the depositional system: a change from an offshore to lower shoreface, to lagoonal-estuarine and -swamp environments with probably some fluvial influence. These are illustrated by the block diagrams A, B, and C. Lithofacies associations D and C suggest a transgressive phase: from tidal flat to upper shoreface.

The thick laminated mudstone with gutter cast sandstone which is slightly bioturbated and shows carbonaceous laminae (lithofacies association A) records depositions in a restricted, offshore, shelfal environment (open-marine) during the early phase of relative sea level rise.

Lithofacies association A may be succeeded in places by the lower shoreface deposits of lithofacies association B (hummocky cross-stratified sandstones), which records sedimentation in wave- and storm-dominated (open-marine) environment, as the relative sea level began to fall. The continual falling of relative sea level led to the deposition of hummocky cross-stratified sandstones (lithofacies association B) to be deposited within the lower shoreface environment.

Suraya and Lambiase (2002) have suggested that the hummocky cross-stratified sandstones of the Sandakan Formation as having been deposited in the lower shoreface zone while Noad (1998) interpreted this lithofacies as sub-tidal tempestites.

The upward transition into lagoonal-swamp and -estuarine deposits is suggested by the presence of lithofacies association F and E. Lithofacies association F suggests deposition in a lagoonal-estuarine with well developed swamp, suggested by the occurrence of coal layers. Lithofacies association E records deposition in lagoonal-estuarine, most probably in a marsh area.

Rahmani (1988) suggests that estuarine systems are characterized by a tripartite style of sand-to-mud-to-sand fill. Dalrymple (1992) propose that most estuaries comprise three zones: (i) an outer zone dominated by marine processes, (ii) a central zone where marine energy is dissipated by fluvial currents, and (iii) an inner, river-dominated zone. The distribution of total energy that produces the tripartite division is more pronounced in wave-dominated estuaries than in tide-dominated systems (Zaitlin and Shultz, 1990). In the case of Sandakan Formation, the occurrence of thick laminated-mudstone with carbonaceous detritus (Facies SDM1) may suggest the central zone of the estuary. The presence of Facies SDS3 and SDC1 associated with Facies SDM1 may be indicative of the inner, river-dominated zone.

Reading and Collinson (1996) suggested that in humid and temperate lagoons, the muds are often rich in organic matter, including plant debris washed in by rivers. The remains of such rich vegetation are typical of low-lying fresh water swampland or lagoonal deposits (Sellwood, 1978; Rangel *et al.*, 2002).

The units overlying lithofacies associations E and F represent the establishment of a tidal flat and an upper shoreface (lithofacies associations D and C). They reflect a rise in the relative sea level: from tidal flat to upper shoreface. The lithofacies association D records deposition in tidal flat. It is represented by a rhythmic alternation of sandstone beds (which are occasionally rippled tops) with lenticular mudstone. These deposits maybe locally cut by intertidal runoff channels, suggested by the occurrence of Facies SDS3 (thin cross-bedded sandstone-shale succession). Noad (1998) suggested a similar interpretation. He interpreted the sandstones of this lithofacies association as having deposited in sub-tidal channel-mouth shoals.

The transition upward into upper shoreface is suggested by the thick clean, cross-bedded sandstone of lithofacies association C. Within the upper shoreface environment storm processes transport sand-grade material whilst fair-weather wave action has a winnowing effect, removing clay- and silt-grade material, resulting in very clean sandstone. This suggestion agrees with the interpretation of Suraya and Lambiase (2002). Noad (1998) indicated that the upper shoreface in Sandakan Formation is absent.

During the time of lithofacies association C, the relative sea level began to rise up again forming progressive upper shoreface environment landward.