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Tertiary Coastal and Shallow Marine Successions of the Sandakan Formation (Sabah), Miri and Nyalau Formations (Sarawak): Facies, Stratification and Reservoir Properties

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Introduction

Siliciclastic shallow-marine deposits form major reservoirs in many hydrocarbon provinces worldwide (e.g. North Sea, Nigeria, Brunei, Venezuela etc.). In Malaysia, they form the main reservoirs in the Malay Basin, Sarawak Basin and Baram Delta Province. Siliciclastic shallow-marine deposits are sedimentary records of the environments between land and sea, and their responses to a variety of forcing mechanisms, such as physical process regime, the internal dynamics of coastal and shelf depositional systems, relative sea level, sediment flux, tectonic setting and climate. In the present work, we investigated the facies and stratigraphic architecture of known shallow marine outcrops in Sandakan (Sabah), Miri and Bintulu (Sarawak) as possible analogue for the offshore hydrocarbon-bearing sequences in the Sarawak, and Malay basins.

Sedimentary Formations, Facies Associations and Stratigraphic Architecture

The Nyalau Formation of Bintulu, Sarawak. The Nyalau Formation (Late Oligocene – Middle Miocene) which is equivalent to Cycle II & III of the offshore hydrocarbon-bearing formation is well exposed in the Bintulu area in Sarawak. The Nyalau Formation consists predominantly of soft to moderately hard, thinly to thickly cross-bedded sandstones alternating with mudstone and sandstone with occasional coal seams. Integrated facies analysis and biofacies studies were carried out on several well exposed outcrops in south Bintulu to characterize the facies, facies associations and biofacies, and to interpret the depositional environment of the successions. Fourteen sedimentary facies were recorded they are; tabular-planar cross bedded sandstone, amalgamated trough cross bedded sandstone, trough cross bedded sandstone, flaser, wavy ripple sandstone, heterolithic sandstone, heterolithic mudstone, bioturbated flaser, wavy-ripple sandstone heterolithic, bioturbated cross laminated sandstone heterolithic, interbedded sandstone and bioturbated mudstone, well bioturbated mudstone, laminated mudstone, carbonaceous mudstone, carbonaceous mudstone and coal, coal and paleosol. These are grouped into six facies associations: i) tidal channel, ii) tidal flat, iii) sand flat, iv) tidal sand bar, v) mangrove swamp and vi) coastal peat swamp. Biofacies data revealed that the sedimentary successions are dominated by mangrove pollen notably *Florschuetzia trilobata* and *Zonocostites ramonae* and commonly associated with marginal marine foraminifera such as *Miliammina fusca* and *Trochammina maceresens* different with the coal facies which content mainly freshwater and/or peat swamp pollen. Based on the integration studies, the sedimentary successions from this area are interpreted to be deposited within tide-dominated estuary with varying degree of fresh water and salinity influx (Zainey Konjing, 2015).

The Miri Formation of Miri, Sarawak. The rock exposed around the Miri town, are of Middle- to Late-Miocene age, and they are part of the subsurface, oil-bearing sedimentary strata of the onshore and offshore West Baram Delta, which have been uplifted and are exposed predominantly as an arenaceous succession. At the Hospital Road-Hillside Garden outcrop, a thick succession of sandstone–mudstone interbedding are well exposed with a total stratigraphic thickness of 34 m. The outcrop is divided into three successions. *Facies succession I:* The first unit is interbedded sandstone-mudstone, very fine-grained and having primary structures of hummocky cross-stratification. It has a total stratigraphic thickness of 8 m. *Facies succession II:* The second unit comprise hummocky cross-stratifed, yellowish brown, well-sorted sandstones interbedded with thin mudstone with a total of 10 m thick succession. Bioturbation and fossils are distributed throughout the unit. *Facies succession III:* The third unit is thick, very fine- to fine-grained, yellowish, well-sorted sandstone with a total of 15 m thick succession. The primary structures are small trough cross-bedding, massive sandstone and hummocky cross-stratified sandstone facies (Numair Siddique, 2015).

The Sandakan Formation of Sandakan, Sabah. The Upper Miocene Sandakan Formation of the Segama Group is well exposed around the Sandakan town and across the Sandakan Peninsular in eastern Sabah. It unconformably

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overlies the Garinono Formation and is conformably overlain by the Bongaya Formation. Seven lithofacies were identified: i) thick amalgamated SCS/HCS sandstone; ii) thin, lenticular interbedded HCS sandstones and mudstone; iii) laminated mudstone with Rhizophora; iv) trough cross-bedded sandstone; iv) laminated mudstone; vi) striped mudstone with thin sandstone and siltstone; and vii) interbedded HCS sandstone and mudstone. 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 *(Khor Wei Chung et al., 2015)*.

The common facies associations displayed within the Sandakan Formation comprises a lower mud–dominated interval, bearing shallow water nannofossil (*Sphenulitus Abies)*, an intermediate interval of thin HCS beds and capped by a thick (4 - 5m) SCS-HCS unit. This upward-coarsening, upward-thickening succession from mudstone-dominated to sandstone-dominated sediment intervals is typical of siliciclastic wave-dominated shoreline that has undergone normal regression, and progradation. The facies successions display bioturbated and non-bioturbated offshore mudstones in the lower part, passing through the HCS storm beds of the lower shoreface, continue through the trough crossbedding of the upper shoreface, pass upwards into the seaward inclined laminae of the foreshore.

Reservoir quality of coastal and shallow marine sandstones

We identified five reccurring sandstone facies in the Sandakan, Miri and Nyalau Formations. These are:

a) hummocky cross-stratifies sandstone (HCSS),
b) herringbone cross-bedded sandstone (HBCBS),
c) trough cross-bedded sandstone (TCBS),
d) flaser- to wavy-bedded sandstone (W-FBS),
e) bioturbated sandstone (BS).

HCSS, HBCBS and TCBS sandstones form the best quality sandstone reservoir in terms of grain distribution, porosity (>15%) and permeability (>250 mD), and its lateral and vertical extend, at outcrop scale (300-500 m extent).