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Petroleum system of the Balingian Province, Sarawak Basin

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The Balingian Province is a proven petroliferous province with a Tertiary petroleum system (Mazlan and Abolins, 1999). Figure 1 is a schematic representation of the petroleum system of the Balingian Province, Sarawak, proposed in this study based on detailed evaluation of the coaly source rocks and interpreted in combination with published data. The Balingian Province is part of the Sarawak Basin which was a foreland basin during the Oligocene-Early Miocene times, and was subjected to active extensional and strike slip tectonics. During the Middle Miocene, the Sarawak Basin underwent a phase of compression, which resulted in the formation of the Balingian Thrust Belt. Later, the Sarawak Basin saw a coastal shelf progradation and passive continental margin outbuilding during the Middle Miocene to recent.

The Balingian oils are derived from Cycles I/II coal and carbargillite source rocks accumulated within a lower coastal plain deltaic sequences dominated by sandstones, shales, and thinly bedded sands and muds, thereby providing intra-formational source rocks, reservoirs, seals, and carrier beds. The onshore extension of these sequences is known as the Nyalau Formation. The coaly source rocks of Cycles I/II are dominated by higher land plant macerals. They are either vitrinite rich (> 80% vitrinite) or liptinite rich including 80 to 60% vitrinite, 15–25% liptinites such as suberinite, cutinite, bituminite, terpene resinite, sporinite and alginite. The dominance of the higher land plant character is also expressed by the geochemical parameters such as waxyness, widespread occurrence of oleanene, high Tm/Ts ratios, and high C_{29}/C_{30} hopane ratios. The originating flora is presumably a thick mangrove belt similar to that presently fringing the Sarawak coastline, which underwent a suitable burial history and adequate organic matter accumulations under tidal influence.

The coaly source rocks have reached early to mid-maturity with regards to the oil window, which is defined here for coals as being %Ro 0.4–1.2. Several features of early oil generation from coals were reported. Among these features are the occurrence of exsudatinite, micrinite, oil haze, oil droplets, framboids, changes of fluorescence intensity, and the impregnation of the epoxy resin by bitumen. The oil window of the Sarawak coals (%Ro 0.4–1.2) has a peak of generation between 0.5% and 0.7%Ro and is subdivided into two generation phases (i) An early phase %Ro 0.4–0.7 is induced by suberinite, bituminite and terpene resinite, and (ii) the second-generation phase %Ro 0.7–1.2 involves sporinite, cutinite, lipid resinite, alginite and other liptinitic macerals. The first phase of generation is more significant due to the abundance of the macerals suberinite, bituminite, and terpene resinite. By considering this for the Balingian Province a larger volume of source rock will have reached maturity and have generated liquid hydrocarbons.

The extent of primary migration is intimately related to the physical changes of coal during maturation. Primary migration passes through a minimum during the plastic stage. Prior to this minimum the first phase of primary migration is eased through the fabric of coal and by the development of hydraulic fractures (exsudatinite crack network). The increase of porosity and brittleness in the post plastic stage enhances the expulsion or the second phase of primary migration. The second phase of primary migration with a greater tendency for gas release is more considerable than the first one that yielded higher amounts of liquid hydrocarbon. Subsequent to expulsion, secondary migration proceeds through conduits materialised by the mesoscale fracturation. The structural complexity of the Balingian Province, the close association of the oil accumulations with the source rocks, and the lateral continuity of sand bodies seem more likely to favour vertical migration as the most effective charging mechanism with some lateral migration through the thinly bedded sands and muds.

Most of the traps in the Balingian Province are structural traps formed as a result of the Middle Miocene compressional deformation. They are E-W folds and structural highs. However, right lateral movements have influenced the structural trends that are close to the West Balingian Line, or Lines parallel to it (170 and/or 150), resulting in WNW trending anticline structures, which form some of the larger oil fields in the Balingian Province. In the east of the province, the major structures trend NE-SW and seem to be related to left lateral movements along the Anau Nyalau Fault or lines parallel to it (010 and/or 030).

Cycle I/II Balingian sandstones, are considered to be the most important reservoirs. They have porosities ranging between 15 and 32% porosity, which decline rather rapidly due to the basinal related compaction, cementation, and geothermal gradient. Furthermore, an internal shear is recognised in the Bintulu sandstones rich in organic matter that probably reduces their quality. Intraformational shale is considered as efficient cap rocks and seals. Faults cutting through this shale could become effective sealing faults, which lead to highly compartmentalised reservoirs, and therefore increase exploration risks and development costs. Reservoirs in Cycles I/II are oil bearing and those of Cycles III and younger are mostly gas bearing; this is probably due to migration, extent of the source rock, as well as the volume of hydrocarbon generated.