Coaly Petroleum Source Rocks in Malaysia – is the Present the Key to the Past?

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INTRODUCTION AND OVERVIEW

Malaysia's three oil-producing regions are: (1) Malay Basin, (2) Sarawak Basin, (3) Sabah Basin (Figure 1). Though, basin evolutions differ somewhat, the petroleum systems remain broadly similar. Other than Central Luconia, which is distinctively a carbonate gas province, the other provinces are characterised by accumulations of oil and gas found within Neogene clastic reservoirs (Figure 2). HC charge was derived principally from a Type III coaly source rock (SR) e.g., (i) in-situ pure coal and/or impure shaly coal, (ii) transported coaly clasts/fragments in channel lag deposits, (iii) finely-dispersed detritus, and also, commonly as coaly laminae/bands, mostly in marine deposits.

MALAYSIA'S CLASTIC PETROLEUM SYSTEMS

Traditionally, it has been a long-held belief that, of the 3 end members (Type I, II, and III), the land plant derived Type III coaly SR is, by far, the most predominantly gas-prone (van Krevelan, 1950). Therefore, the role of coal as a viable source for oil has been a lengthy and contentious debate. But, in the context of Malaysian clastic petroleum systems, the presumably gas-prone Type III coaly SR could not explain for the large oil accumulations.

The bulk of so-called Tapis crude in the Malay Basin is sourced largely from post-rift Group I and H coals (Madon et al., 2004, and 2006) (Figure 3). In the Sarawak Basin, coal and coaly shale seem to be the main SR for the oil, especially in the offshore Balingian Province and the highly prolific West Baram Delta. Biomarker fingerprints of oils from the Balingian offshore fields were geochemically typed to underlying Cycle I-III coals (Madon et al., 1999). Hakimi and Wan Hasiah (2012) reported that Nyalau Fm. coals (Cycle I-III equivalent) from onshore Balingian Province are rich in liptinite (>35%), and possess good liquid HC-generation potential, supported by high Hydrogen Index (HI 350-510).

SR in the Sabah Basin occurs more as disseminated terrigenous organic matter (OM) in mudstone, but also commonly as coaly-carbonaceous laminae/bands within silty sandstone that was dispersed by fluvio-deltaic systems into the marine setting. The SR, though lacking in richness (TOC 1-1.5%), was compensated by good OM preservation from rapid sedimentation/burial coupled with a relatively thick cumulative succession. Moreover, SR as TOC-enriched laminae in siltstone-sandstone favoured efficient expulsion. Geochemical and fingerprint studies of Sabah oils reaffirmed the link to a typically Type III/II coaly SR (Madon et al., 1999).

Bearing some local facies variation, crude oils from Sabah-Sarawak are also mostly light and volatile, often verging on condensates, characteristically sweet, somewhat waxy, very typical of land plant origin, much alike the premium-grade crude from Malay Basin (Figure 4). It is noteworthy that Malaysian oils, grouped as Tapis grade, fetches the highest price in the international market, due to its highest gasoline content per barrel of crude.

LINK BETWEEN COAL AND OIL - HISTORICAL BACKGROUND

MacGregor (1994) and Todd et al. (1997) highlighted that the first link between oil and terrigenous organic matter was made by Hedberg (1968), that, high-wax and low-sulphur oils are commonly associated with non-marine, often coal-bearing strata. Oil-prone sequences have been recognised as key SR in the SE Asian -

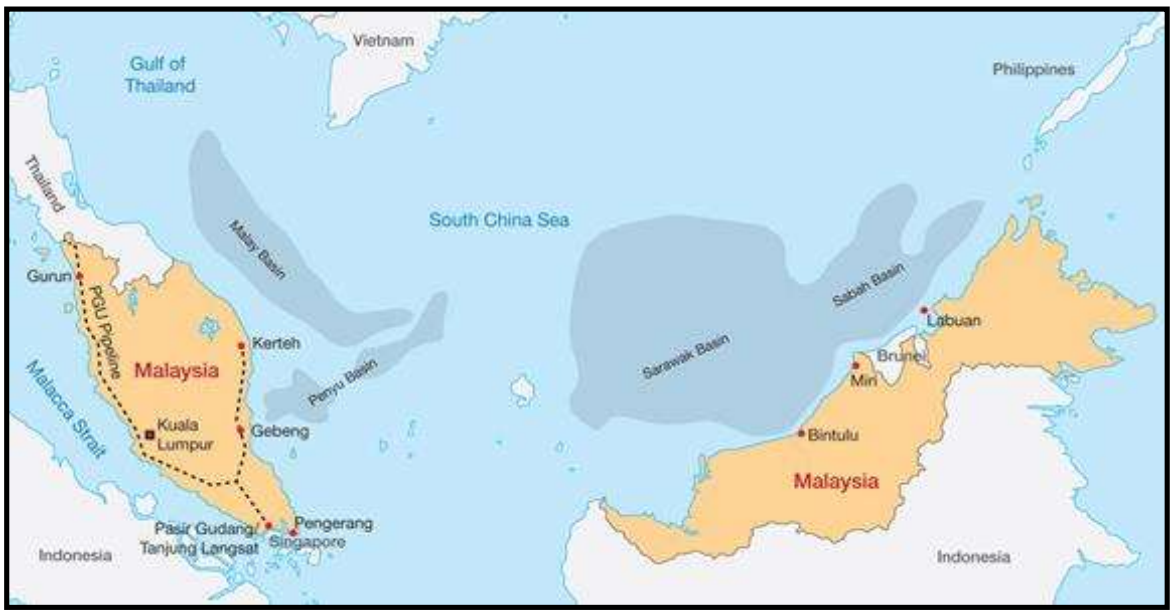


Figure 1. *Malaysia's 3 HC-producing basins - (1) Malay Basin, (2) Sarawak Basin, (3) Sabah Basin (Madon et al., 1999).*

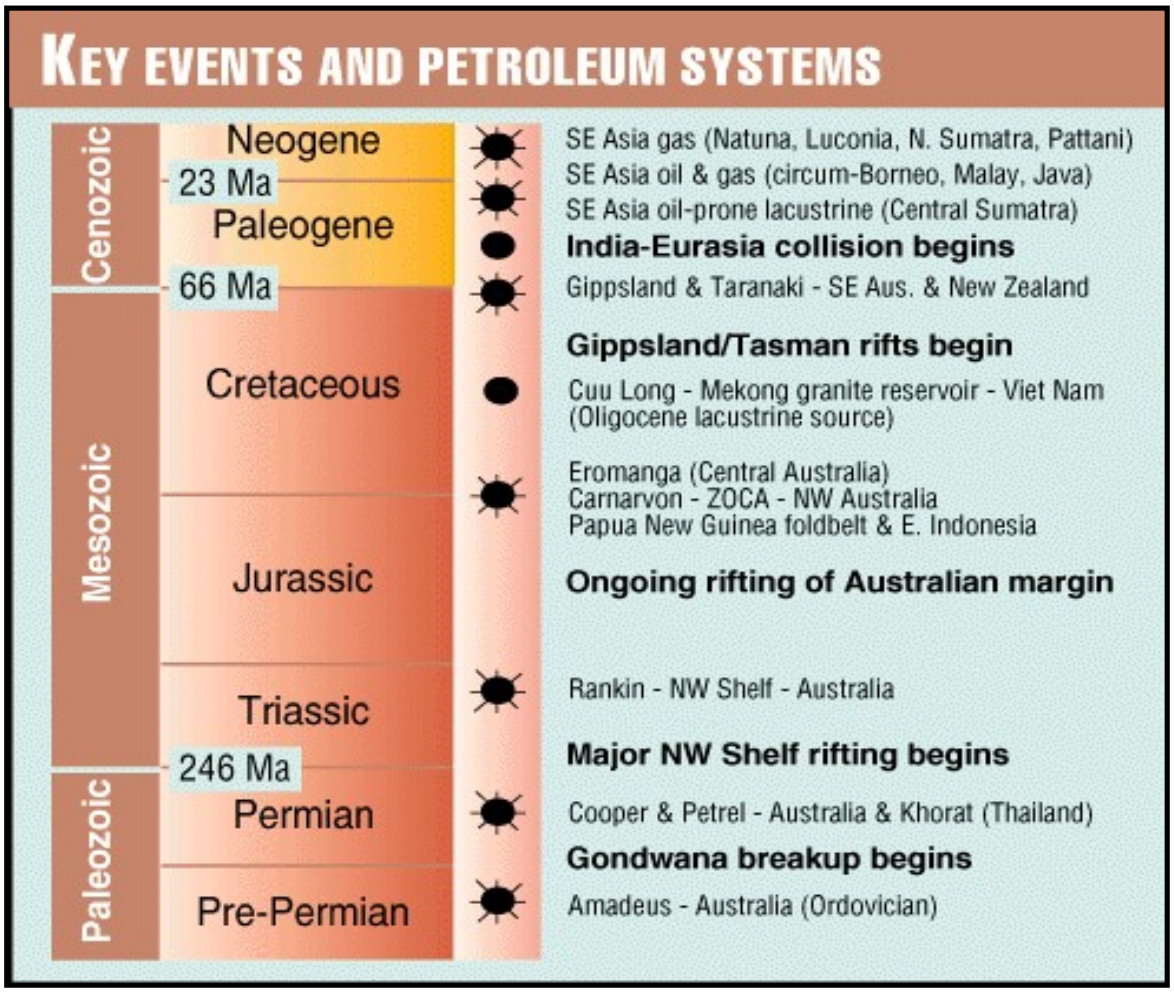


Figure 2. *Major tectonic events & petroleum systems of SE Asia, Australia & New Zealand. NB: the relatively very young (Cenozoic) petroleum systems of SE Asia in general, & largely Neogene for C. Luconia, Circum-Borneo (inclusive NW Borneo) & Malay basin (Oil & Gas Journal website).*

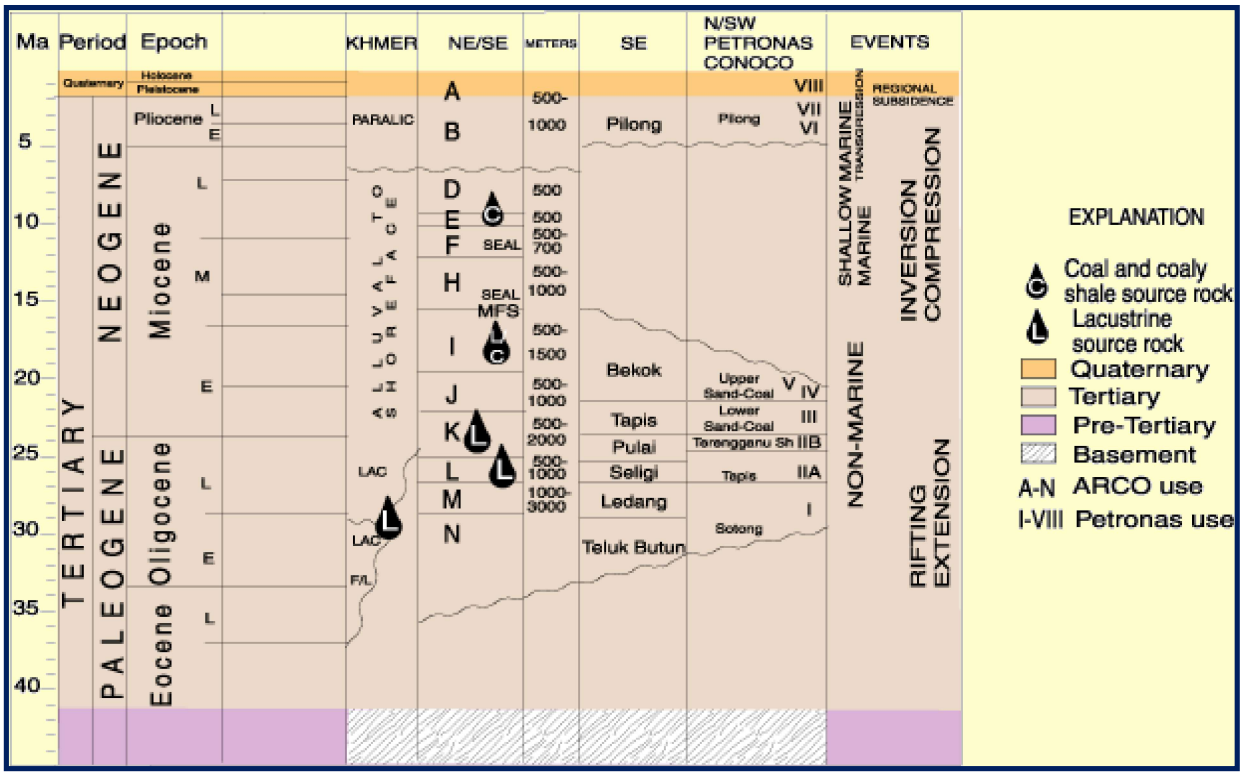


Figure 3. *The two active source rocks in Malay Basin – (i) syn-rift lacustrine shale (Group L & K) mainly in South Malay Basin, (ii) coal/coaly shale (Group I & H) largely in the Greater Malay Basin (Madon et. al. 2004).*

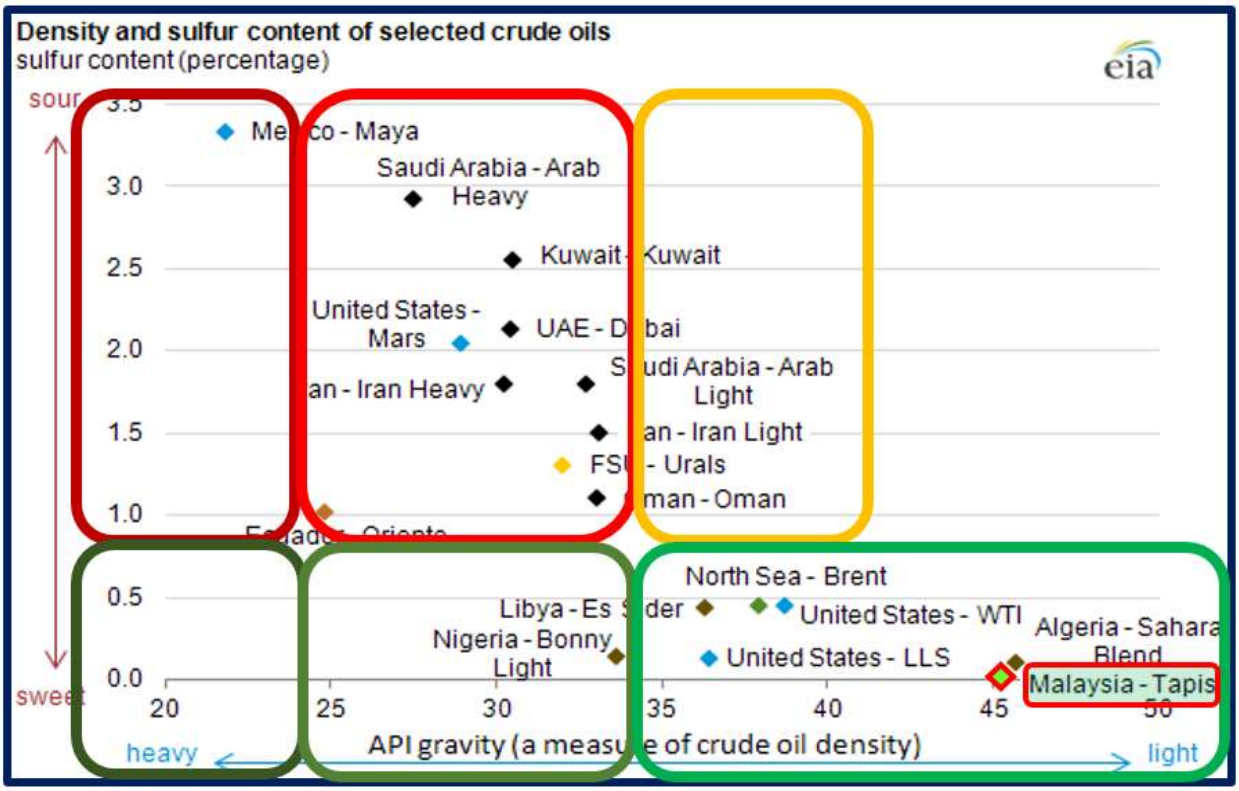


Figure 4. *Malaysia's premium Tapis crude - world's most expensive crude. Typically, light (43-45o API), exceptionally low-sulphur (0.04%), high gasoline/bbl (US EIA / Energy Info Admin. website, 2012).*

Region, including Australia and New Zealand, a unique feature of coals from this part of the world (Fleet and Scott, 1992). In the Gippsland Basin of SE Australia, maximum oil generation was reported to derive from coals with high content of perhydrous vitrinite (Moore et al., 1992).

SE ASIAN COALS AS PETROLEUM SOURCE ROCKS

Davis et al. (2007) carried out an extensive study on oil-generation potential of Tertiary coals from western Indonesia (Figure 5) whereby >500 samples across 14 basins were analysed. The key findings are: (i) Tertiary coals have a remarkable range of petroleum potential, (ii) the most hydrogen-rich coals, with concomitant high-ash content, deposited in submerged mires, are most oil-prone; (iii) equally H-rich coals, but with low-ash, deposited in raised mires, tend to be more gas-prone; (iv) the favourable type of vitrinite (detrovitrinite) is more important than the liptinite content; (v) the greater the degree of degradation, the greater the petroleum potential; (vi) degree of degradation is controlled by water table relative to surface of the peat; (vii) climate, depositional environment or tectonic setting are unlikely to significantly influence on degree of degradation. Sykes (2001) reported that paralic coals, originated from mangrove swamps, influenced by seawater, commonly associated with increased sulphur, may also enrich the H-content in the vitrinite.

Hence, according to Petersen and Rosenberg (2000), an in-depth understanding of local environmental factors that control HI and the types of vitrinite of coals during peat-forming process is crucial towards establishing distribution of oil-prone coaly SR from more gas-prone facies. Such additional info to fine-tune SR input in basin modelling work may enhance the confidence level in charge prediction by highlighting oil sweet spots towards improved exploration success rates in wildcats drilling.

MODERN SWAMPS AND PEATLANDS AS ANALOGUES

Climatic condition in equatorial SE Asia is thought to remain largely unchanged since Oligocene. Therefore, the study of modern tropical swamps and peatlands, as precursors to coal deposits, may improve prediction on HC-generation potential of coaly SR. Distribution of present-day peatlands is broadly influenced by: (i) high rainfall (Figure 6), and (ii) low-lying coastal plains, especially in Borneo and Sumatra, where large tracts of coastal swamps occur (Figure 7) (after Wosten et al., 2008).

In the NW Borneo, extensive peat swamps along lower coastal plains of modern Baram Delta were studied e.g. by Anderson (1964), Anderson and Muller (1975), Esterle (1990), Esterle and Ferm (1994), (Figs. 8 and 9). Raised mires up to 20m thick were recorded. Rapid delta growth was estimated at ca. 10m/year (Sandal, 1996).

CONDITIONS FOR PEAT DEVELOPMENT

For peat to form, biomass (OM) production must exceed its chemical breakdown. Peats have a wide range in degree of decomposition. Kurbatov (1968) quoted: “Formation of peat is a relatively short biochemical process under influence of aerobic microorganisms in surface layers of the deposits during periods of low subsoil water. As the peat, formed in peat-producing layer, becomes subjected to anaerobic conditions in deeper layers, it is preserved and shows comparatively little change with time”. Therefore, the presence of either aerobic or anaerobic conditions decides whether any biomass will accumulate and in what form. Distinction is made between more aerated (oxygenated) forest peats, thus more decomposed, and peats formed under swampy conditions, with strongly anaerobic conditions. In forest peat, lignin and carbohydrates appear to be completely decomposed so it generally has a low content of such organic compounds, a precursor to thin, laterally more continuous and high-ash sapropelic oil-prone (Type III/II) coal. Whereas under submerged swamp conditions, peats are characterised by high contents of cutin and presence of much unaltered lignin and cellulose, precursors to thick, more localised, and very low-sulphur and low-ash humic gas-prone (Type III) coals.

Most tropical peats develop in low-lying coastal swamps (anaerobic conditions) that prevents microbiological activity needed for chemical breakdown of OM. This largely accounts for accumulation of partly decomposed biomass in the form of peat. The anaerobic conditions are created by a specific hydro-topography, whether marsh, swamp, bog or mire, whence the properties depend on many environmental factors, including climate, landform, local geology and hydrology, but all (of the peat’s depositional condition - *Ed*) have severe toxicity; others e.g. mangrove swamps have high-sulphur and sodium which may reduce oxidation.

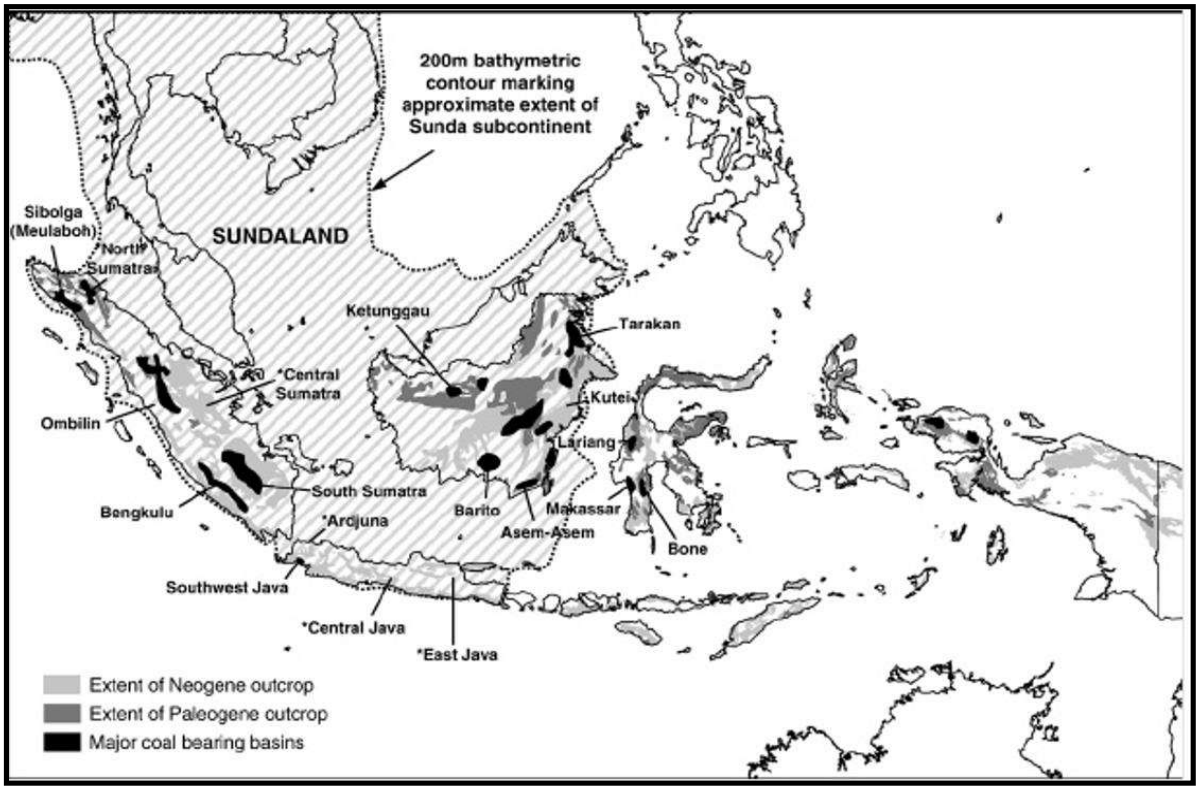


Figure 5. *Major coal deposits of SE Asia. Most of the coals are found in Sumatra & Borneo (Davies et al., 2007).*

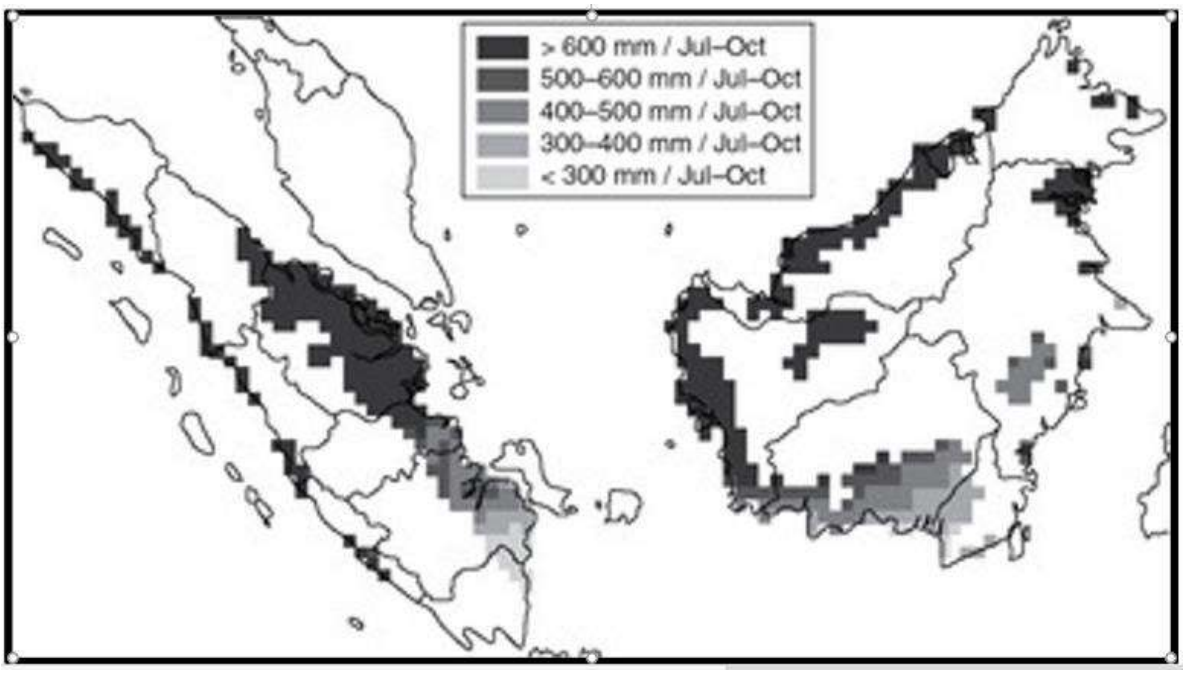


Figure 6. *Rainfall distribution in Borneo & Sumatra where most of SE Asian peatlands are found. Rainfall has a significant impact on peat growth. (Source: Wikipedia website, 2018).*

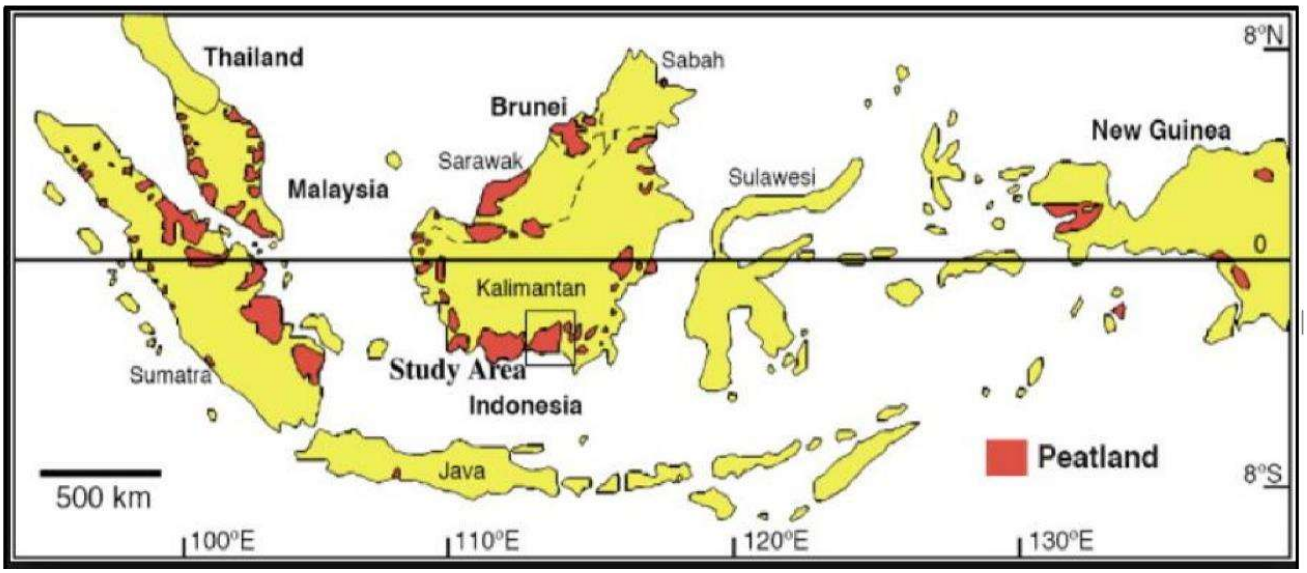


Figure 7. *Major peat areas (in red) in the Malay-Indonesian Archipelago (Wosten at al., 2008).*

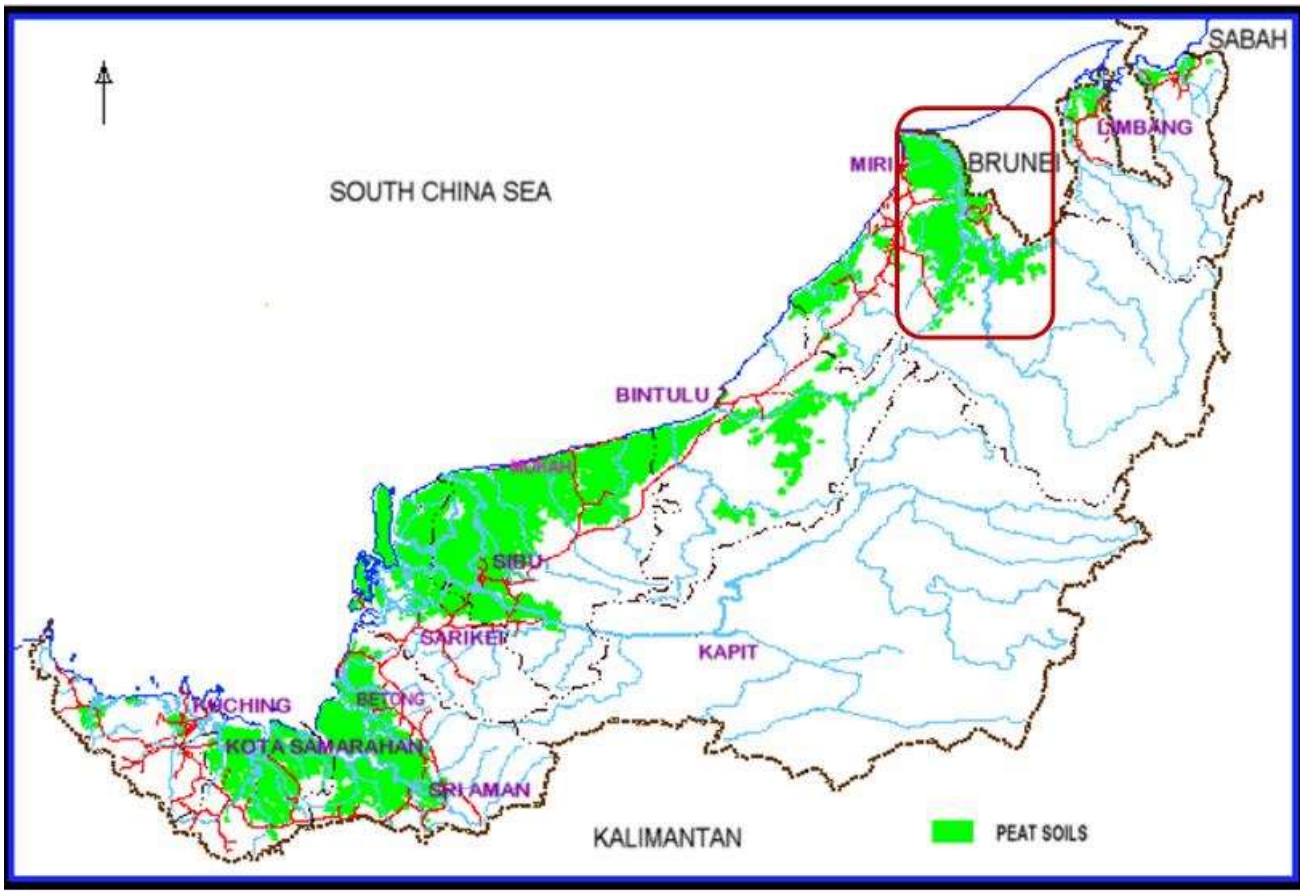


Figure 8. *Peak swamp deposits in Sarawak, NW Borneo. The modern Baram Delta peat swamps is located within the brown box (Forest Dept. of Sarawak website, 2018).*

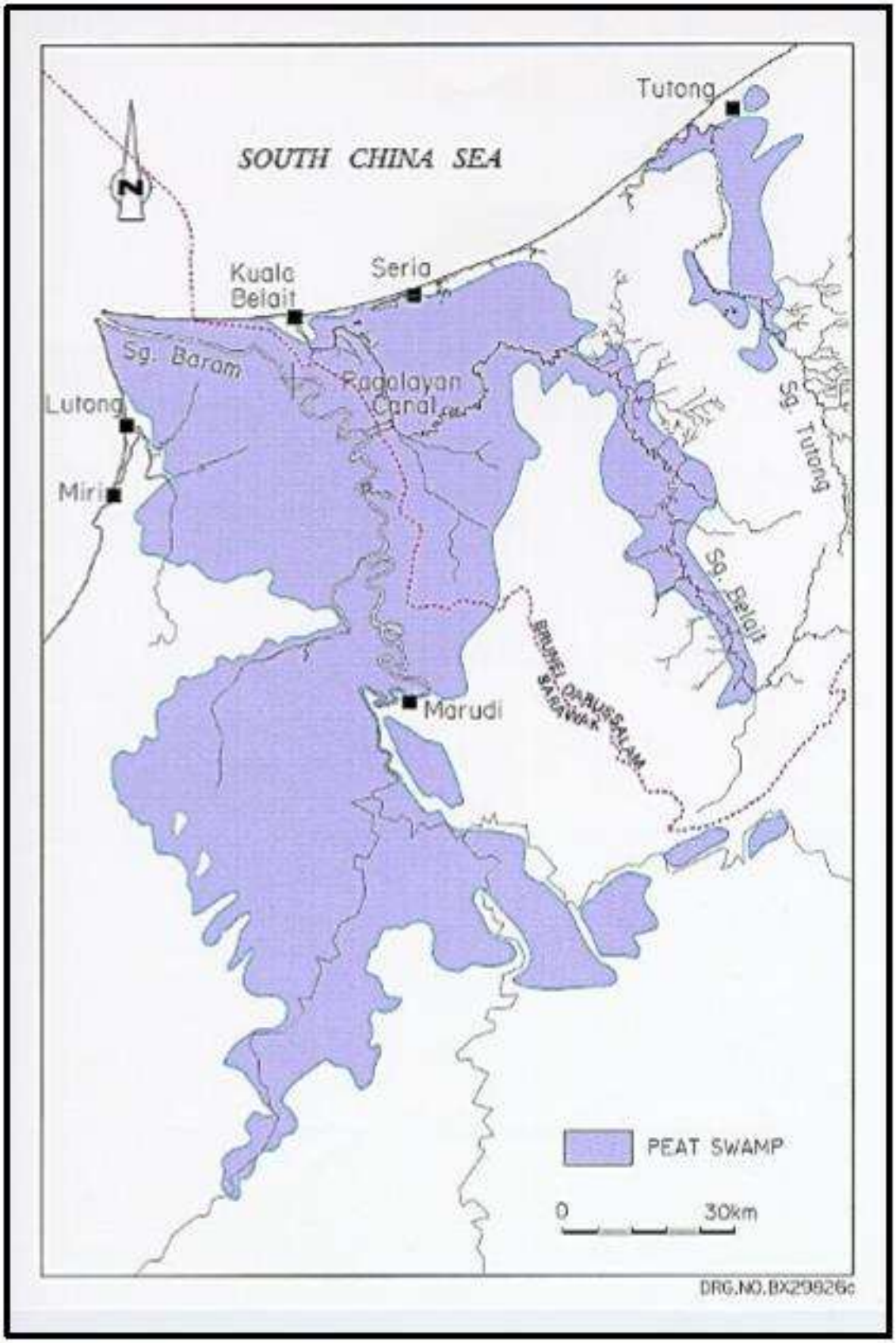


Figure 9. *Peat swamps of modern Baram Delta (Anderson & Muller, 1975).*

PEAT STAGES DEVELOPMENT

According to Moore & Bellamy (1974), peat growth is initiated if water balance at a site is characterised by the equation:

Inflow = Outflow + Retention

Modifying it for climatic factor:

Inflow + Precipitation = Outflow + Evapotranspiration + Retention

Peat growth starts within the retention volume, with peat acting as an inert body, displacing its own volume of water. Peat accumulated in the initial depression is primary peat (Figure 10). As peat accumulates beyond level at which water is drained from the basin, it no longer acts as an inert mass but as an active reservoir holding a volume of water against drainage. Development of primary peats reduces surface retention of the reservoir. Secondary peats develop beyond confines of the basin or depression (Figure 10). Tertiary peats develop above the physical limits of groundwater, the peat itself acting as a reservoir holding a volume of water by capillary forces above the level of main regional groundwater table (Figure 10). This reservoir forms a perched water-table fed only by rain.

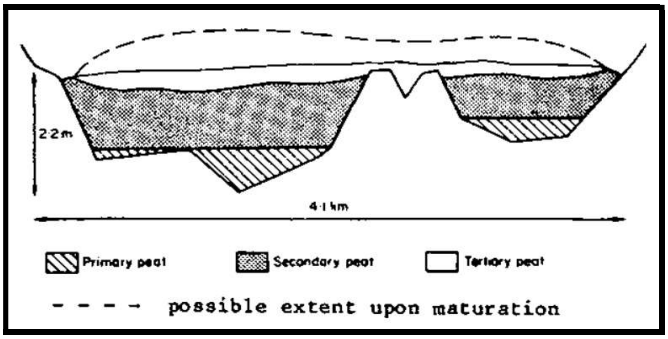


Figure 10. *Profile of a ridge raised mire (Moore & Bellamy, 1974). The height of the component copulas depends in part on the area of the mire & in part on the climate.*

In tropical and monsoon climates, evapotranspiration is usually too great to cause development of secondary and ands, unless there is excessive rainfall, well distributed over the year, combined with favourable topography, with a complete lack of drainage, giving continuous wet conditions. Such conditions are found in coastal lowlands surrounding Sunda Flats (i.e. Lower coastal plains surrounding present-day Sunda landmass around Malaysia & Indonesia - *ed*). Topography is invariably basin-shaped within natural drainage blocked by natural barriers.

Most modern tropical peats are <10,000 years old; SE Asian coastal peats generally <6,000 (Andriesse 1974; Driessen 1977). Sarawak peat (dated on 14C) indicates a maximum 4,300-5,400 (Anderson, 1964; Esterle, 1990). This coincided with melting of ice at beginning of Holocene resulting in marked sea level changes, which affected low-lying coastal regions, changing depositional behaviour of rivers, particularly in estuaries & deltas.

Quantity & nature of peat accumulating in a depression are very much related to depositional behaviour of streams affecting the depression. If, e.g., streams change their silt load, say seasonally, or there were other longer-term fluctuations, OM are contaminated with mineral deposits (shaly coal). Changes in stream bed can also influence actual site where mineral deposits accumulated (mud bands/intercalations). Types of vegetation and characteristics of developing peat depends strongly on nature of the water feeding the ecosystem.

Figure 11 depicts various stages distinguishable in peat swamp development (Moore and Bellamy, 1974), based on studies of mire ecosystems by Kulczynski (1949). As already indicated, the flow of water is extremely important for the type of peat developing, since changes in water-flow signifies change from one stage to another.

Stage 1. Initial deposition of peat - 2 alternative conditions to inflowing water: (i) a large flow of water brings sediment from outside. This, coupled with a slow rate of peat formation due to strong oxygenation through large influx of water, results in production of a heavy sinking peat, and water flow is concentrated near the surface, (ii) a small water flow and less material is added from outside, so, with a faster rate of peat growth, a light, floating peat (gyttja) is produced and water flows below a floating mat.

Stage 2. Accumulation of peat tends to canalize the main flow of water within the basin, leaving some areas (hatched) subjected to effects of moving groundwater during periods of excessive flow only. Two alternatives are recognized: (i) whole peat mass inundated, (ii) peat mass not inundated and floats.

Stage 3. Continuing vertical and horizontal peat growth causes the largest part of basin above influence of inflow. Water supply mainly restricted to rainfall directly on swamp surface with some seepage from surrounding areas. Only those areas immediately lying along main drainage tracts

within the swamp may show a slow continuous flow.

Stage 4. Continuing peat growth leaves most of swamp unaffected by moving water but inundation occurs when water-table in basin rises from heavy rainfall.

Stage 5. Peat surface risen, no longer affected by seasonal groundwater fluctuations. By this mature stage, a large part of the domed peat is above surface of the surrounding flood plains (Andersen, 1964). Even a slight morphologic elevation can dramatically reduce ash due to sediment bypass and clay flocculation around the margins (Esterle and Ferm, 1994). Dome-shaped peat surface possesses its own perched water table fed by rain.

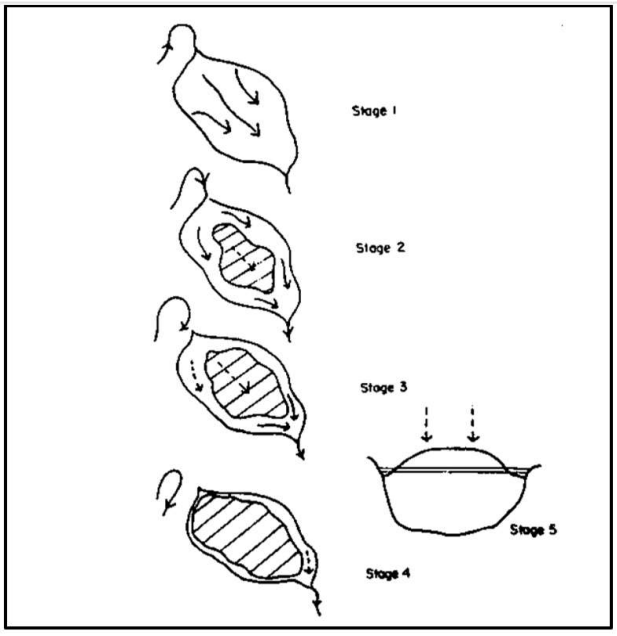


Figure 11. Model of the succession of mire types (Moore & Bellamy, 1974).

Stages (1-3) fed to some degree by water from surrounding areas results in topogenous peat, precursor to oil-prone coal. Late stages (4-5) with almost all minerals available recycled within the ecosystem, results in ombrogenous peat, precursor to gas-prone coal.

Andriesse (1974) observed such successive stages (Figure 11) in deep peat swamps development in coastal areas based on field info in the Sarawak Lowlands of Anderson and Muller (1975) whereby development of primary, secondary and ands can be recognized, and a division can be made into topogenous and ombrogenous stages. Anderson (1964) also provided evidences of former islands of low elevation now completely covered by And deposits.

Figure 11 illustrates that in a strong depositional environment, as is often found in a monsoonal climate, the evenly-spread accumulating mineral deposits will slowly raise the floor of the basin & prevents complete blockage of drainage. In such cases peat development is either absent or found only in small depressions when favourable hydro-topographic conditions are present.

Many peat deposits in tropical areas show in cross-sections the various stages described. Bottom layers have rich plant species because of generally richer nutrients than overlying layers. Generally, there is a gradual impoverishment in mineral content of the peat, particularly in major elements (Ca, Mg, K & P). Therefore, depth of the peat is an important indicator of fertility. Type of the peat, whether topogenous or ombrogenous, indicates the expected fertility.

RATES OF PEAT ACCUMULATION

Climate plays a decisive role in dynamics of processes involved, e.g., in tropics, greatest rate of build-up of silt barriers in rivers. Also, much larger amounts of water generally pass through tropical systems (rainfall >4,000 mm/year).

Forest-type peats dominate in SE Asian tropical lowlands. The deepest layers of Sarawak forest peat (4,300 years old) accumulated at a rate of 1m/214 years (Anderson.1964); 1m/333 years (3,900 years old), but 1m/455 years in last 2,300 years. Vertical succession in coastal lowlands is commonly characterised by mangrove species followed by transitional, brackish water communities in later stages & evolve to freshwater swamp communities & finally replaced by a poor Shorea albida monostand on ombrogenous raised peat domes.

In the coastal lowlands of wet tropical belt, although forest peat predominates, there are exceptions because the type of peat also depends on development stages, site characteristics and climate. This shows that the degree of degradation is controlled by water table relative to surface of the peat. Degradation increases oil-generation potential.

SUMMARY

Oil-prone Tertiary coals are recognised as key SR throughout SE Asia, a unique characteristic of coals from this part of the world, e.g., the bulk of oils from NW Borneo & Malay Basin were geochemically-typed to coaly SR. During peat

development stages, environmental factors that control HI & types of vitrinite, have direct implications on whether the coals tend to be more oil-prone or gas-prone. Changes in water flow signifies progression from one stage to another.

SE Asian coals possess a wide range of petroleum potential. The most oil-prone are high-ash & H-rich coals deposited in low-lying swamps within initial depressions (topogenous peat). Low-ash but equally H-rich coals, deposited in raised mires (ombrogenous peat) tend to be gas-prone. The favourable type of vitrinite (detrovitrinite) is more important than liptinite amount. Increased sulphur in paralic coals from mangrove swamps may also enrich H-content in the vitrinite.

Large tracts of coastal Sunda Flats, especially in Borneo & Sumatra, typically started as submerged mineral-rich mangrove swamps, followed by transitional brackish-water peat, that gradually evolved into freshwater forest-type peat, but still subjected to frequent flooding. Finally, the mature peat is risen above seasonal flood levels, replaced by mineral-impoverished peat domes, fed solely by rain. Decomposition in either aerobic or anaerobic conditions determines if peat will accumulate & in what form? Higher degradation occurs during the earlier peat development stages in "submerged" & anaerobic forest-type peat than the later stages of more aerobic raised peat. This shows that the degree of degradation is controlled by water table relative to surface of the peat. Degradation increases oil-generation potential.

Therefore, earlier-formed low-lying forest peats, often inundated by floods, tends to result in oil-prone (Type III/II) coals; whereas later-formed raised peat domes, risen above seasonal flood levels, result in gas-prone (Type III) coals. This intimate link between peat development stages to either oil-prone or gas-prone coals does indeed reaffirm the general notion in geology that "The Present is the Key to the Past"!

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