

## Tertiary coal-bearing heterolithic packages as low permeability reservoir rocks in the Balingian Sub-basin, Sarawak, Malaysia

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**Abstract:** Between 1930 and 1940, oil shows as well as gas that existed in the reservoir in gaseous phase rather than in solution (free gas) were found in the Mukah area. However, none of the discoveries were developed. Drilling results suggest that oil shows are common, while gas shows are present at deeper depths. Exploration requires a knowledge of heterogeneities in the rock. This paper is an introduction to a thematic set on the characterization of strata which acts as a reservoir for hydrocarbon gas and focuses on two main topics: (1) heterolithic facies and (2) diagenesis. The Balingian Sub-basin contains more than 6 km of sediment infill and is believed to be an important hydrocarbon kitchen. The coal-bearing sedimentary packages are composed of shale or mudstone, alternating with sandstone layers of varying lateral extent and locally intercalated with coal beds. These were deposited in Upper Miocene tide-influenced or tide-dominated deltaic and estuarine environments. However, some coals and carbon derived from the hydrogen-rich parts of plants such as cuticles and spores or sporinite might have generate and expel oil. Diagenetic events were an additional aspect that affects the reservoir quality. Clay cements have grown as a combination of grain-coating or pore-lining and pore throat blocking clots. The pore throat blocking cements caused a rapid decrease of porosity, so that it had an effect on the permeability similar to that of ductile grain compaction. The grain-coating and pore-lining cements in contrast caused a slight reduction in the permeability as the pore-throats were only partially blocked. A better understanding of the coal-bearing heterolithic strata through assessment may lead to the discovery of new unconventional hydrocarbon reserves.

**Keywords:** coal-bearing, heterolithic strata, reservoir characterization, Balingian basin

### INTRODUCTION

Heterolithic stratification produced by delta progradation has received much attention in recent years. This stratification is challenging for reservoir description and effective field development because it constitutes ‘marginal’ reservoir units. According to the studied facies, the stratification is mainly formed by lateral accretion of point bars in meandering channels (Barwis & Makurath, 1978; Clifton, 1983; de Mowbray, 1983; Thomas *et al.*, 1987; Smith, 1988). Despite its presence in fluvial environments, heterolithic stratification also appears to be particularly abundant in tide-influenced settings. A close genetic relationship for this paleoenvironmental condition is attributed to systematic variations in reservoir rock organic facies development. The accumulation of reservoir rocks occurs in a rapidly varying environment strongly influenced by paleogeography. Therefore, a good understanding of the paleogeographic evolution is also crucial to the exploration success. This paper focuses on reservoir description, uncertainties, both static and dynamic, of heterolithic deltaic-estuarine succession in the Balingian Formation. These heterolithic units were formed in tide- or wave-influenced through to tide-dominated depositional environments during the Upper Miocene (Fromm & Stengele, 1994), in which the sediment delivered to the deltas, estuaries or embayments consisted

dominantly of mud or silt. The authors have identified the eligibility of coal-bearing heterolithic strata as good reservoir rocks, based on the occurrences of their depositional structure, visible porosity and permeability distribution in reservoir assessments. The main objectives of this study are to identify and describe the occurrence and nature of each facies of coal-bearing heterolithic sediments, and to analyze the diagenetic history of the clastic sediments in relation to reservoir quality. In this study, a total of thirteen samples from the Balingian and Begrih Formations, Balingian Sub-basin, Sarawak were analyzed using integrated petrological and petrophysical analysis.

### REGIONAL BACKGROUND

#### Study Area

The study area is located in the coastal region of Sarawak, Malaysia along the Mukah-Selangau road in the Mukah-Balingian district (Figure 1). The area has widespread rock exposures of coal-bearing heterolithic strata. The study focused on the Balingian Formation, which is the older rock along the Mukah-Selangau road (Hutchison, 2005). The Balingian province is chosen because it has recognized gas-prone source rocks with coals and organic-rich clays combined with sandstones representing a multiple source and reservoir rocks.

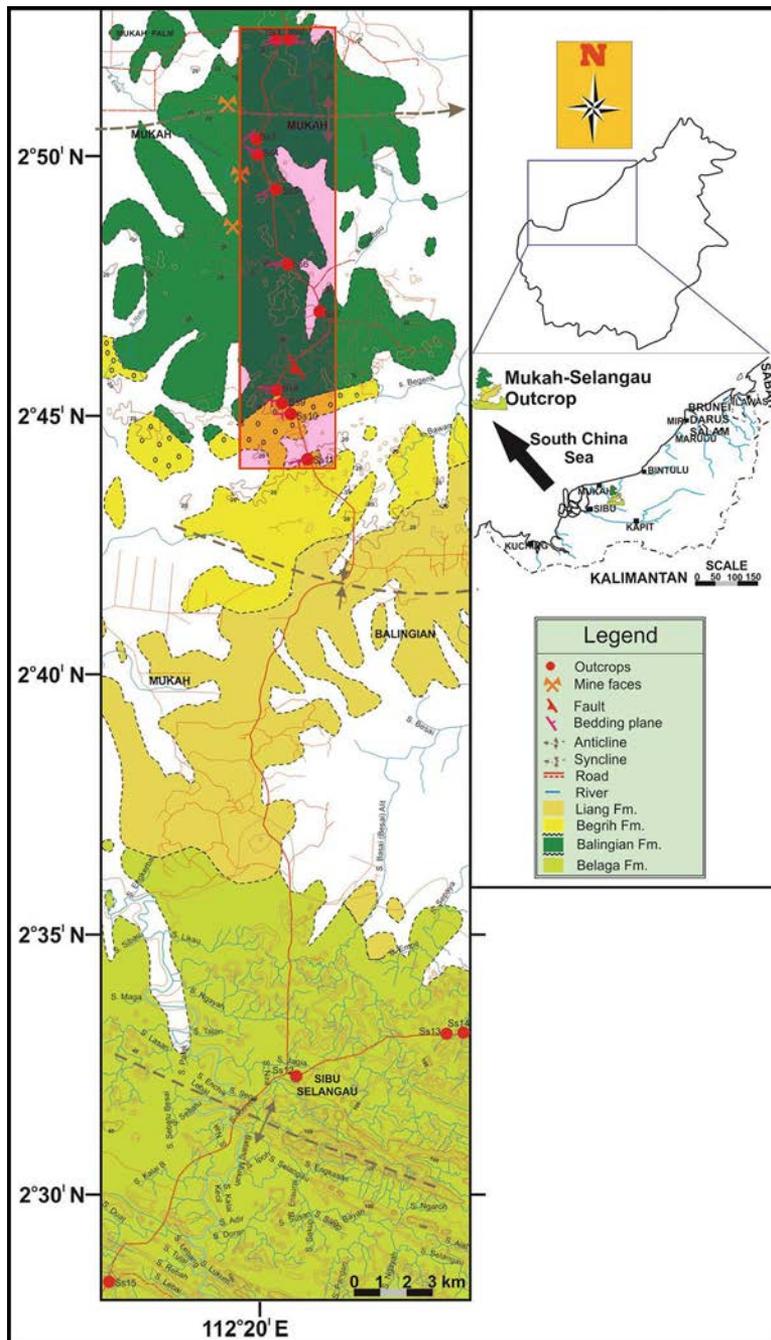


Figure 1: Map showing the location of outcrops in the study.

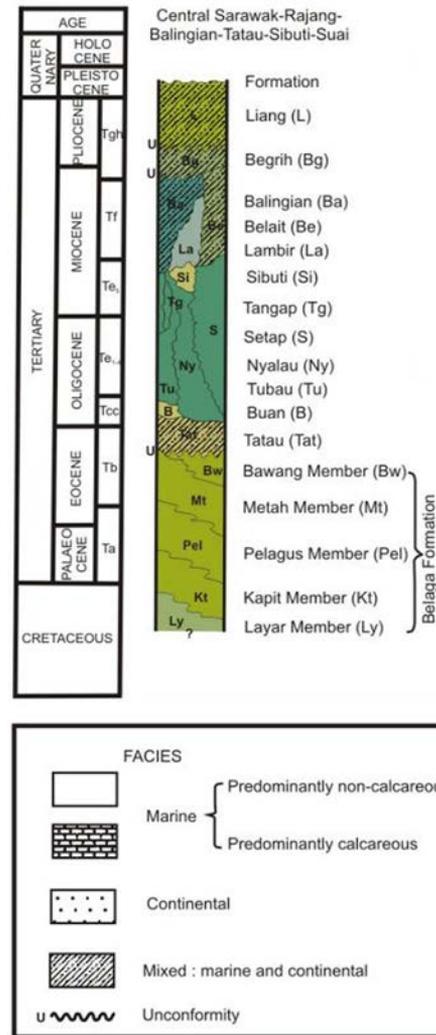


Figure 2: Generalized stratigraphy of central Sarawak: Rajang- Balingian-Tatau-Sibuti-Suai (modified after Wolfenden, 1960).

### Geologic Setting of The Balingian Sub-basin

The Balingian Sub-basin has an area of about 27,000 km<sup>2</sup>, where 30% of it is onland (Swinburn, 1994). The Balingian Sub-basin provides a good example of how paleogeography controls source rock deposition (hence, quality) and subsequently the hydrocarbon distribution. This basin contains more than 6 km of siliciclastic sediments infill that also contains coal. They are believed to be important hydrocarbon kitchens for the oil and gas fields located on the surrounding intrabasinal structural highs and on their up-dip margins (Hutchison, 2005). The Mukah- Balingian area is build up by a succession of coal hosting molasse sediments of Upper Miocene and Pliocene age. The molasse

rocks can be divided into three units (Wolfenden, 1960): Liang Formation (Upper Pliocene); Begrih Formation (Lower Pliocene) and Balingian Formation (Upper Miocene) (Figure 2). The rock succession in the Balingian Formation is consisting of mudstone, shale, siltstone, sandstone and conglomerate with interbedded lignite. This formation is unconformably overlain by the Begrih Formation, which is dominated by thick layers of homogeneous mudstone, claystone and more rarely sandstone, conglomerate and coal than in the Balingian and Liang Formations. Minor tectonic activity occurred during Miocene times affecting the Balingian Formation. Thinner successions of the Begrih and Liang Formation unconformably overlies much of this

coastal areas. The extensional phase that occurred further to the west of the Tatau Province created a pervasive set of small N-S oriented normal faults and E-W oriented folds.

**METHODOLOGY**

The field investigation was located in the Mukah-Balingian Region (Central Sarawak) which involved mapping on the scale 1:50,000 for almost 50 km across the whole Mukah-Balingian region. The field investigation was on the sedimentology of the rocks. Field data collection included measuring the stratigraphic successions of rocks. Heterolithic rock samples were collected for laboratory analyses focussing on reservoir assessment, including petrographic analysis of twelve samples using optical microscopy on blue dyed thin sections to easily recognize the pores. Eleven samples were examined using X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). Petrophysical properties were determined from several samples using Mercury Injection Capillary Pressure (MICP).

**RESULTS**

**Facies Association and Palaeo-environment**

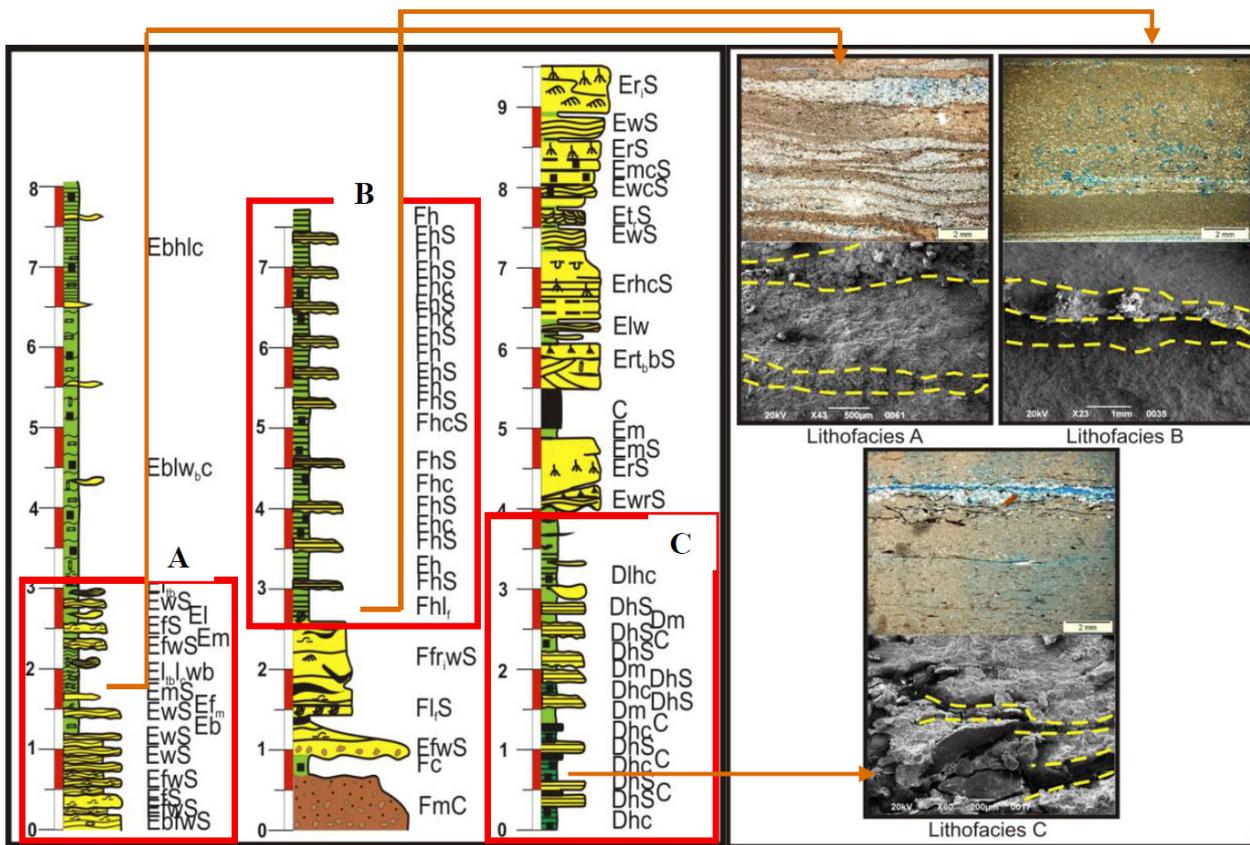
A detailed facies examination of the Neogene succession was undertaken in both the Balingian and Begrih Formations. Detailed logging allowed for a series of facies associations for the rhythmic alternation of two or more facies on a small-

scale (typically 0.5-5 m or generally <10m). The successions of heterolithic stratification are summarised in Table 1 and illustrated in Figures 3 to 6. Four different facies have been identified and simplified into two facies associations. Each facies is characterised by a dominant flow process that allows indirect interpretation of their palaeo-depositional settings (fluvial-related deposits and tide-related facies associations).

**Tide-related facies association**

**Facies A (FC A): Intertidal flat**

This facies cycle is specifically attributed to the intertidal flat deposits that consist of thin sheets of sand bodies, overlaid by alternating of sandstone and mudstone, followed by thickening upward of mudstone units. The sandstones are mostly very fine-grained and commonly display the geometry of lateral accretion. Mudstones are grey to dark grey, massive to thick-bedded, and often have parallel laminations of sand and carbonaceous material. Heterolithic bedding is dominant, consisting of flaser (typically bifurcated-wavy or, more rarely, wavy) and wavy bedding. Low angle tabular cross laminations are present as physical sedimentary structures (Figures 6, B, D). Sandstone intraclasts are common. Thick mudstone (e.g. 6.5-8 m) commonly comprise a few, laterally extensive bodies in a single outcrop. Mixed fresh and brackish water trace fossil assemblages are represented by the occurrence of predominant *Planolites* isp, followed by lesser amount of robust J-shaped specimens



**Figure 3:** The short section of sedimentary log shows typical appearance of heterolithic lithofacies from the Balingian Formation. Examples are taken from rock exposures. Each lithofacies is shown in one representative thin section photomicrograph (above) and SEM image (below).

of *Arenicolites* isp., fresh water specimens of *Scoyenia* isp. as well as marine specimens of *Skolithos* isp. (Figure 6A) and *Ophiomorpha* isp. The assemblage includes very simple dwelling structures produced by opportunistic suspension feeders. Sediments deposited in intertidal flats adjacent to wave-dominated shorelines can also contain simple vertical burrows (*Skolithos*) and U-shaped vertical burrows (*Arenicolites*) (Bromley and Asgaard, 1979).

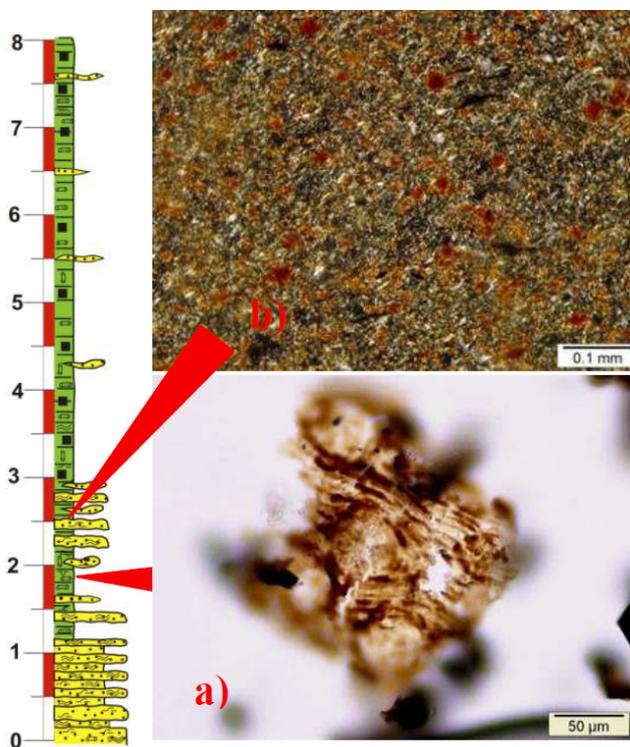
Ichnodiversity and degree of bioturbation decrease slightly towards the top of the package. The abundant of bioturbation at base implies the increasing of oxygen availability as well as the decreasing of organic carbon preservation, and vice versa to the top succession. It most likely represents the lower intertidal sand flat in a lower- to middle-estuarine setting. *Arenicolites* isp. and *Ophiomorpha* isp. are excellent indicators of tidal flats. Tidal flat deposits

commonly exhibit diverse biogenic structures, even when present in low abundance. Tidal influence is evidenced by the presence of alternating flaser and wavy bedding through differing bedload transport mechanism during tidal flow and suspension settlement during slack-water periods (Reineck and Wunderlich, 1968; Klein, 1971). Common presence of planar cross-lamination is suggestive of sandwave migration during periods of high energy currents (Dalrymple, 1992). The presence of soft sediment deformation structures suggests downslope movement of sediment across bar slopes.

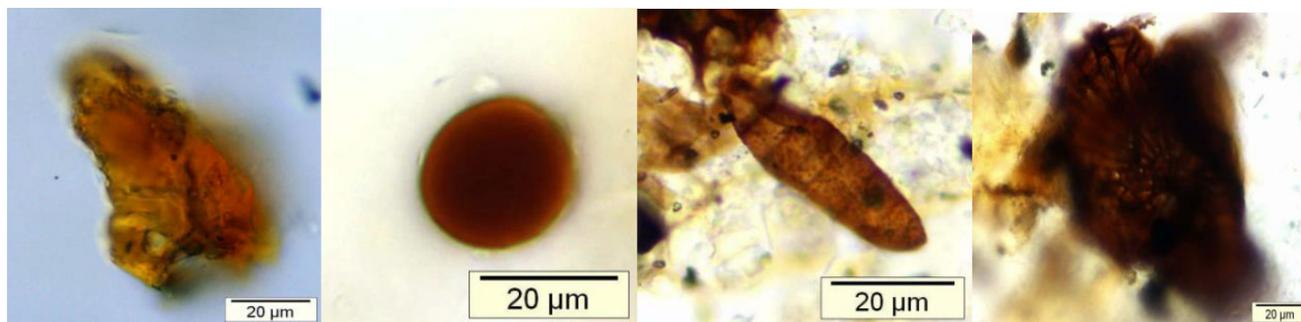
Sanding- to muddying-upward vertical trends suggest probable fluctuations in sea levels rather than changes in sedimentation rates. Preservation of organic matter was dominated by massive opaque phytoclasts with lesser amount of cuticles, palynomorphs, lath and cross-hatch shaped phytoclasts, gymnosperm tracheid fragments, xylem ray tissue, fungal and dinoflagellate cysts (Tyson, 1995). The presence of dinoflagellate cysts together with abundant plant tissues supports the interpretation of brackish water environment near to the coast (Tyson, 1995).

#### Facies C (FC C): River mouth

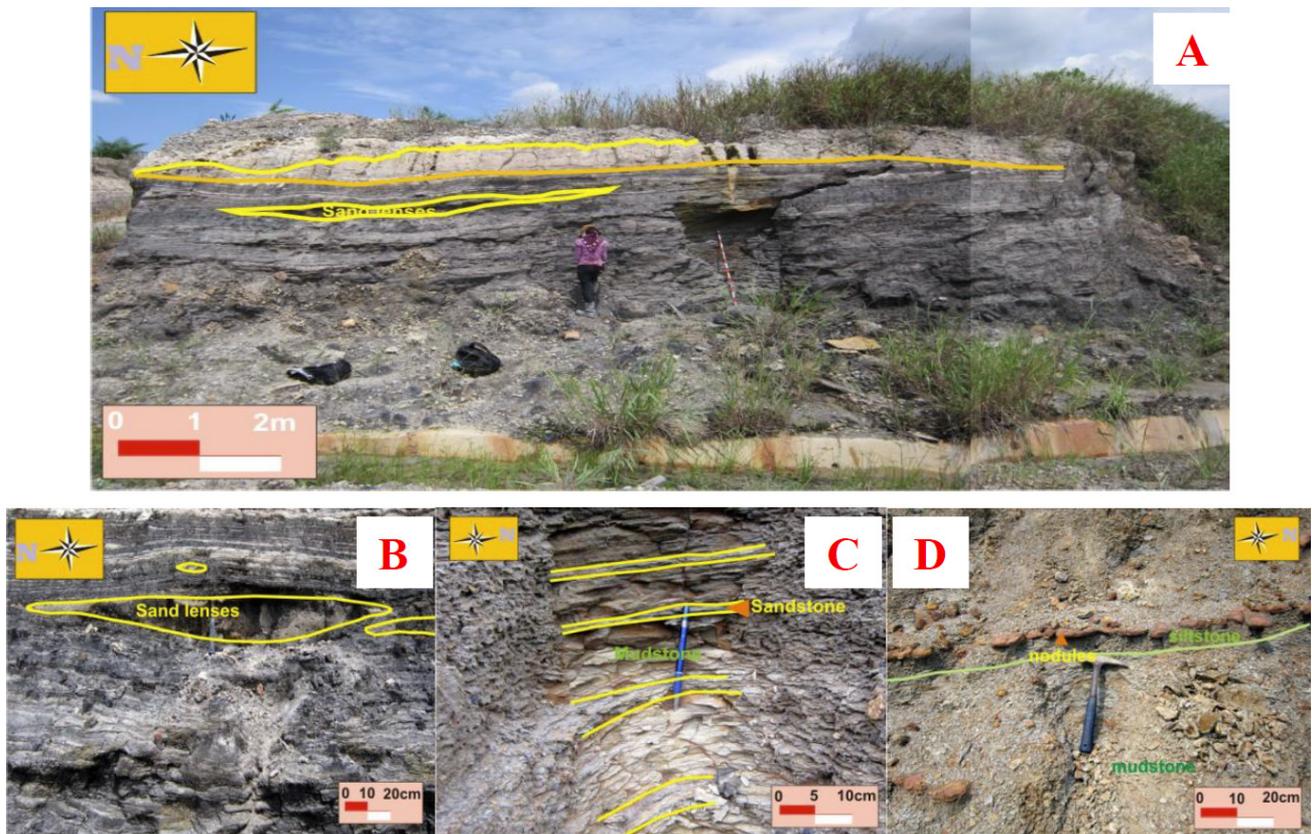
This facies is made up of metre-thick beds of interbedded mudstone, carbonaceous mudstone and very fine grained sandstone with subordinate coals (Figure 6A). Upward-fining trends occur to varying degrees, both as individual sandstone-mudstone-coal couplets of heterolithic strata and in overall successions of this assemblage (facies thickness 4m on a single outcrop). Sandstone lenses are common (Figure 6B). Mudstone, horizontal mud laminae and flattened sand lenses are present. Thin sandstones are typically massive, grey in colour, mostly silty to very fine grained and also contain carbonaceous materials. Log impressions have no fossil or bioturbation, but disperse amber was commonly found embedded within the carbonaceous mudstone. The amber occurs in association with lignite and is best preserved in subaqueous or water-logged environment of river mouth (Iturralde-Vinent, 2001). This facies is interpreted as having been deposited in a river mouth with low salinity setting. The heterolithic stratification is interpreted as having been produced by point-bar accretion (Jablonski, 2012) as a dominant structure adjacent to an upper intertidal channel. Detail observation of organic matter under transmitted light microscope suggests that amber, a resinite maceral is present. Amber is a fossil resin of higher plants, as



**Figure 4 (a):** Etched vitrinite cryptocorpocollinite surrounded by cryptotellinite present as typical maceral vitrinite that can generate gas. **(b)** More brackish water environment is also evidenced by the occurrence of iron-siderite.



**Figure 5:** From left to right- micro-photographs of resin, marine prasinophyte phycocyst, fungal and multicellular fungal fruiting body.



**Figure 6:** (A) Photographs showing heterolithic facies of one of the outcrop from Balingian Formation. (B) Details of sandstone sand lenses within fine alternating sandstone-mudstone-coal. (C) Close-up of interbedded horizontally laminated mudstone and horizontally laminated sandstone layers. (D) Reddish iron-cemented nodules found embedded within interbedded mudstone and siltstone. Slightly oxygenated water is evidenced by the presence of iron nodules.

extracellular exudations on the plant (stem or leaf) surface (Figure 5 left, Tyson, 1995). They are most typically associated with coniferous gymnosperms (Araucariaceae and Pinaceae) (Iturralde-Vinent, 2001). The sedimentary organic matter is dominated by phytoclast of cuticles followed by palynomorphs, fungal fruiting bodies, root cortex tissue and marine prasinophyte phycoma (Figure 5).

#### Facies D (FC D): Upper delta plain

This facies cycle consists of predominantly gray carbonaceous mudstone interbedded with subordinate brownish gray iron-cemented siltstone of the Begrih Formation (Figure 6D). On a single outcrop thick mudstone sheets (e.g. 3 m) commonly comprise a few, laterally constrained iron-cemented siltstone bodies. No animal traces were detected and implying decreasing oxygen availability as well as increasing organic carbon preservation. The cuticles, spores, pollens and fungal bodies form the dominant phytoclasts based on optical analysis. Freshwater condition is detected from the occurrence of the freshwater alga *Petrococcus* with other undescribed freshwater algae, while marine influence is recognised from the presence of marine prasinophyte phycoma and dinoflagellate cysts (Tyson, 1995).

#### Fluvial-related deposits

##### Facies B (FC B): Low energy flood plain

Poorly exposed, decimetric to metric thick mudstone and very fine grained sandstone characterise the facies cycle of the low-energy flood plain (Figure 6C). Poor preservation of fine horizontal lamination was observed in the succession. The poor quality of the exposure has obscured some details. Trace fossils were not detected. However, encrustation of vascular plant leaves was observed at the base succession of the flood plain. This facies is interpreted to record deposition under low-energy fluvial current flow, and hence may be attributed to a flood plain environment. The paucity of bioturbation supports the interpretation of a freshwater setting. Similar to facies cycle D are the typical cuticles, spores, pollens and fungal bodies present as the dominant sedimentary organic matters. The marine prasinophyte phycoma and dinoflagellate cysts are negligible. It can be inferred that organic matter were preserved in a slightly oxygenated fresh water environment.

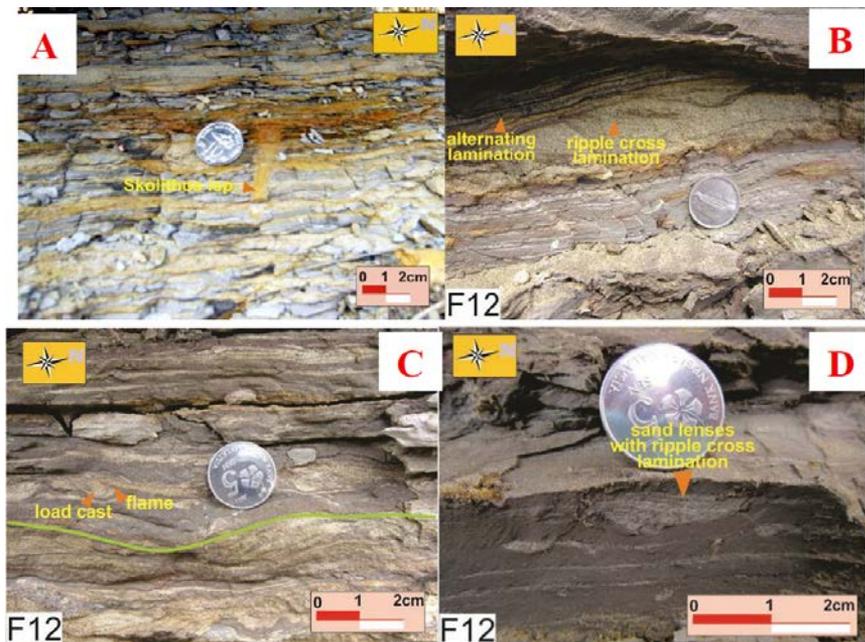
#### Diagenetic aspects

Aspects related to diagenesis were studied using petrographic thin sections and SEM analysis. Overall, macroporosity in the heterolithic sedimentary packages

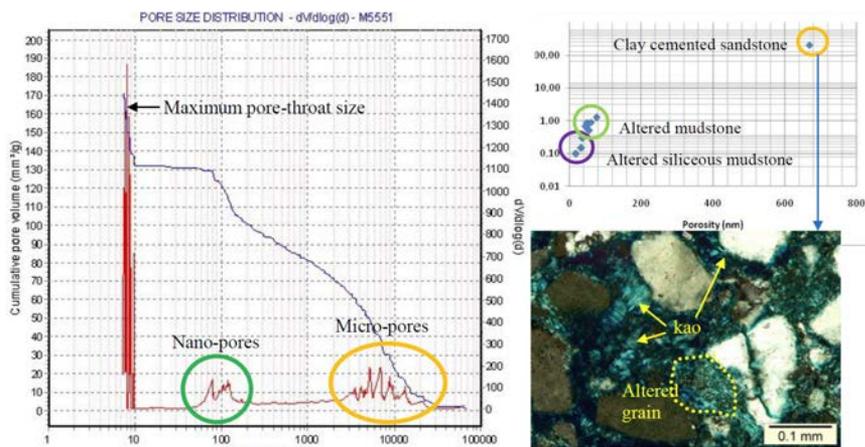
were mainly dependent on the presence of sand-sized grains (recognized as sand lamination and lenses). The distribution of pore sizes are mostly bimodal and polymodal (Figure 8), with a common pore diameter of 10 nm (called as nano-pores; Rouquerol *et al.*, 1994). Most of the macropores were connected, thus giving good permeability. The micro-pores are commonly found in between clay platelets, pyrite framboids and within carbonaceous matter. They are commonly found as isolated pores, except for intraparticle organic matter pores that are connected in 3D (Loucks *et al.*, 2009). Both macro and micro-pores were reduced by diagenetic events during burial. The diagenetic history of the Late Miocene to Early Pliocene heterolithic strata was dominated by compaction, cementation, dissolution and replacement of authigenic minerals (summarized in Table 2). During burial, diagenesis controlled the spatial distribution of permeability due to the growth of grain-coating and infilling clay cements. Furthermore, high temperatures would normally lead to quartz precipitation, while numerous framboidal and sucrosic pyrite might create micro pores (Figure 9). However, ductile components (in the form of clay matrix, mica and carbonaceous material)

would control the amount of quartz cement, because they inhibit its growth (Ali, 1981).

Effective porosity is essentially a function of the porosity and the degree of connectedness of the individual pores. Porosity is diminished by a of variety diagenetic processes. Cementation itself may be characterized by the way that the cement grows in the pore network. Pore-lining and grain-coating cements tend to form approximately equal thickness as euhedral fringes to detrital grains (Ali, 1981). Pore-filling cements, such as clay, pyrite, subordinate siderite and quartz overgrowths tend to occupy pore spaces and partially or totally block pore throats. It has been shown theoretically and empirically that for a given amount of porosity loss (through cementation), pore-filling cements are more detrimental to block the pore spaces than grain-coating and pore-lining cements (Pittman, 1979). Compaction may also be subdivided by the way the detrital sand grains respond to compression. Thus permeability diminishes as porosity is lost and as pores are isolated from one another. Analysis of the effective porosity data reveals that the quantity of the detrital clay matrix and cementation had a profound impact on the flow capacity.



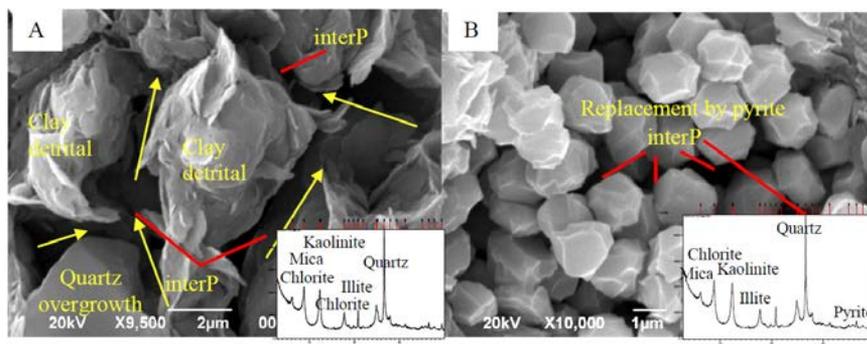
**Figure 7:** (A) Bioturbated mudstone with abundant wavy sand lamination. (B) Most common sand lense with internal ripple-cross lamination. Sand lamination occasionally found alternating with mudstone. (C) Concave-up load cast was associated with flame structure. (D) Preservation of very fine sand lenses and lamination. It is noted that ripple-cross laminations were observed within sand lense.



**Figure8:** Polymodal distribution of diameter pore size from shale samples of the tidal channel facies, Balingian Formation. Pore size ranges from micro to nano-meter and mainly dispersed among clay platelets (such as kaolinite).

**Table 1:** Facies cycles (Fc) characterization of heterolithic strata and palaeo-environment interpretations.

Lithofacies	Lithology	Geometry and large - scale (0.5-1 m thick) sedimentary structures	Small-scale (<50cm) sedimentary structures	Fossils/ bioturbation	Paleocurrent pattern	Depositional process	Depositional environment
A	Flaser and wavy bedded sandstones occur as superimposed very fine and fine-grained, overlaid by alternating mud and sandstones hence grades upward to thick muddy unit	A sheet type of sandstone, followed by upward-thickening profile of mudstone with low-angle inclined clinoform. Inclined heterolithic strata	Wavy to horizontal lamination and bedding, mud flaser with minor lenses and internal micro-cross lamination. Local scour and flame present near to the base of this assemblage	<i>Scoyenia isp.</i> , <i>Arenicolites isp.</i> , <i>Skolithos isp.</i> , <i>Planolites</i> and locally found <i>Ophiomorpha</i>	Unidirectional flow (dominated), recognized from micro-internal cross lamination	Migration of subaqueous and slack-water sediment fallout	Intertidal flat
B	Dominantly carbonaceous mudstone with subordinate very fine-grained sandstone	Thin layer of sandstone embedded in mudstone, followed by thick sheet of mudstone. Sheet types of heterolithic strata	Planar lamination of carbonaceous material in mudstone	Encrustation of vascular plant leaves at the base	None	Suspension deposition under fluctuating energy conditions	Low energy, floodplain
C	Interbedded mudstone, carbonaceous mudstone and very fine-grained sandstone with subordinate coals Mudstone: Bluish grey clay Carbonaceous muds: dark to blackish grey Ss: grey, silty to very fine-grained Coal: brownish black	Whole assemblage of heterolithic strata (HS) with sheets of tabular HS bodies.  Isolated lenticular/ ribbon like channel, commonly filled with sandstone	Horizontal lamination in sandstone	None, but amber present (derived from resin-producing trees)	Sufficient number of paleocurrents not obtained. Horizontal lamination suggest laminar flow by current alignment	Sediment fallout	River mouth
D	Dominantly carbonaceous mudstone with subordinate siltstone	Thin layer of siltstone embedded in thicker mudstone	Planar lamination of carbonaceous material in mudstone. Hard iron-cemented mudstone and siltstone are common	None	None	Suspension deposition under fluctuating energy conditions	Upper delta plain



**Figure 12:** Examples of SEM and XRD results for the Balingian and Begrih formations. (A) Rigid grain covered by quartz overgrowth may strengthen grain from further compaction and preserve the pores. Yellow arrows represent permeable zone. (B) Detail intercrystalline pyrite in inter particle pores (interP).

**DISCUSSION**

Coal-bearing heterolithic facies are sedimentary packages with a strongly bimodal grain-size distribution, typified by low to high frequency alternations of mudstone and or shale layers with sandstone layers and numerous coal intercalation in which layer thicknesses are commonly at the centimetre to decimetre scale (Figure 3). The coal most probably belongs to the humic type and is therefore low for oil generation but provides for a higher amount of natural gas (gas prone) (Swinburn, 1994). Several common aspects can be identified as a guide to future field developments in the Mukah-Balingian region. Sedimentary heterogeneities

of the heterolithic facies of the Balingian Formation has a significant effect on gas generation (as source rock) caused by moderate to high proportion of carbonaceous material and on fluid flow (as reservoir rock) because thin sandstone layers generally increase pore connection. Micropores are largely observed among plates of kaolinite, chlorite and ribbon-like illite as well as sucrosic pyrite. This pore types seem isolated.

The low-permeability problems could be solved by hydraulic fracturing to open the pore throats. Fortunately, the degree and nature of diagenesis indicate shallow to intermediate burial diagenesis. This preserved the



permeability and was not only limited to quartz cementation preserving the pore throats.

### CONCLUSIONS

There are four important facies that could be classified as heterolithic stratification. Most of those facies have been deposited under slightly oxygenated conditions, except for the intertidal facies (facies A) which has been deposited under more oxygenated condition. Paleoenvironment was interpreted from the bioturbation, mineralogy composition and sedimentary organic matter.

Mechanical compaction is one of processes that was affected by depositional texture and mineralogical composition. In a shallow burial, mechanical compaction is the most significant process of diagenesis that reduced the pores significantly.

The cementation and alteration of secondary minerals was found to have partly to totally plugged the pore throat and left only micro- to nano-pores. The abundance and proportion of detrital clay matrix and the effect of burial diagenesis define the occurrence of pore types and their sizes. Pore size distribution suggested that micro- and nano-pore sizes are commonly found between clay platelets, pyrite framboids and within the carbonaceous material.

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### REFERENCES

- Ali, S.A., 1981. Sandstone Diagenesis Application to Hydrocarbon Exploration and Production. Company confidential, Gulf Science & Technology Company. Geology & Interpretation Department, Department Report No. 4231R006, Pittsburgh, Pennsylvania, pp. 1-130
- Barwis, J. H. and J. H. Makurath, 1978. Recognition of ancient tidal inlet sequences: An example from the Upper Silurian Keyser Limestone in Virginia. *Sedimentology*, 25, 61–82.
- Bromley, R.G. and Asgaard, U. (1979). Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. *Palaeogeography, Palaeoclimatology & Palaeoecology*, 28, 39-80.
- Clifton, H. E., 1983. Discrimination between subtidal and intertidal facies in Pleistocene deposits, Willapa Bay, Washington. *Journal of Sedimentary Petrology*, 53, 353–359.
- Dalrymple, R.W., 1992. Tidal depositional systems, In: Walker, R.G., and James, N.P., (eds.) *Facies models-response to sea-level changes: St. John's, Newfoundland, Canada*, Geological Association of Canada, p. 195–218.
- de Mowbray, T., 1983. The genesis of lateral accretion deposits in recent intertidal mudflat channels, Solway, Firth, Scotland. *Sedimentology*, 30, 425–435.
- Fromm, R. and Stengele, F., 1994. Geology and Coal Potential of The Mukah-Balingian Region, Central Sarawak (NW Borneo), Department of Mineralogy, University of Karlsruhe, Kaiserstrabe, 12 76131 Karlsruhe Germany, 45 p.
- Hutchison, C.S., 2005. *Geology of north-west Borneo, Sarawak, Brunei and Sabah*. Elsevier. Amsterdam.
- Iturralde- Vinent, M.A., 2001. Geology of the Amber Bearing Deposits of the Greater Antilles, *Caribbean Journal of Science*, 37, 141-167.
- Jablonski, B.V.J., 2012. Process Sedimentology and Three-Dimensional Facies Architecture Of a Fluvially Dominated, Tidally Influenced Point Bar: Middle McMurray Formation, Lower Steepbank River Area, Northeastern Alberta, Canada, Queen's University, Kingston, Ontario, Canada, pp.62-230
- Klein, G. DEV., 1971. A sedimentary model for determining paleotidal range: *Geological Society of America Bulletin*, 82, 2585–2592.
- Loucks, R.G., R. M. Reed, S.C. Ruppel, and Jarvie, D.M., 2009. Morphology, genesis, and distribution of nanometer-scale pores in siliceous mudstones of the Mississippian Barnett Shale: *Journal of Sedimentary Research*, 79, 848–861.
- Pittman, E. D., 1979. Porosity, diagenesis and productive capability of sandstone reservoirs, In: P. A. Scholle and P. R. Schluger (eds.) *Aspects of diagenesis: SEPM Special Publication 26*, p. 159–173
- Reineck, H.E., and Wunderlich, F., 1968. Classification and Origin of Flaser and Lenticular Bedding : *Sedimentology*, 11, 99-104
- Rouquerol, J., D. Avnir, C. W. Fairbridge, D. H. Everett, J. H. Haynes, N. Pernicone, J.D. F. Sing, and K. Unger, 1994. Recommendations for the characterization of porous solids. *Pure and Applied Chemistry*, 66, 1739–1758.
- Smith, D.G., 1988. Modern point bar deposits analogous to the Athabasca Oil Sands, Alberta, Canada. In: deBoer, P.L., van Gelder, A., and Nio, S.D. (eds.) *Tide-Influenced Sedimentary Environments and Facies*. Dordrecht, Reidel Publishing Co., p. 417-432.
- Swinburn, P., 1994. Structural Styles in The Balingian Province, Offshore Sarawak, Abstract of American Association of Petroleum Geologists International Conference & Exhibition, Kuala Lumpur, Malaysia, 21-24 August 1994, American Association of Petroleum Geologists Bulletin, 78, 62
- Thomas, R. G., D. G. Smith, J. M. Wood, J. E. Visser, E. A. Calverley-Range, and E. H. Koster, 1987. Inclined heterolithic stratification– Terminology, description, interpretation and significance. *Sedimentary Geology*, 53, 123–179.
- Tyson, R.V., 1995. *Sedimentary Organic Matter Organic facies and palynofacies*, Chapman & Hall, London, pp. 157-162
- Waples, D.W., 1985. *Geochemistry in Petroleum Exploration*; Boston, International Human Resources Development Corporation, 232 p.
- Wolfenden, E.B., 1960. *The Geology and Mineral Resources of The Lower Rajang Valley and Adjoining Areas, Sarawak*, The Government Printing Office, Kuching, Sarawak, Memoir 11