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# Organic petrographic characteristics of Tertiary (Oligocene–Miocene) coals from eastern Malaysia: Rank and evidence for petroleum generation

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ABSTRACT

Oligocene to Miocene coals from eastern Malaysia were analysed to evaluate their regional ranks, and petroleum generative potential. The current study performs organic geochemical characteristics of the coals and identifies macerals based on their organic petrographic characteristics as observed under reflected white light and blue light excitations. The coals are characterised by relatively high hydrogen index values between 282 and 516 mg HC/g TOC. This indicates that these coals are dominated by Type II to mixed Type II–III kerogens, and are thus considered to be generated mainly oil-prone and limited gas-prone. This is supported by the presence of significant amounts (11–31% by volume) of oil-prone liptinite macerals. Suberinite is among the most common of the oil-prone liptinite macerals in coals. These coals likely are to be potential petroleum sources, thus, where the former is abundant, waxy oils and naphthenic oil might be expected. This has been supported by the distribution of n-alkyl chains within kerogen pyrolysates, predicting the generation of a mainly paraffinic and paraffinic–naphthenic–aromatic (P–N–A) high wax oils. The coals are thermally early-mature and coal rank in the region is subbituminous A to high-volatile bituminous C, possessing vitrinite reflectance in the range of 0.50%–0.67%. This maturity has a considerable influence on the proximate analysis, particularly on a relatively low moisture content and relatively high fixed carbon and low volatile matter contents. Although these onshore coals are thermally early mature for petroleum generation, the stratigraphic equivalent of these sediments offshore is known to have been buried to deeper depth and could therefore act as potential source rock for mainly oil with minor amounts of gas.



## 1. Introduction

Coals in Malaysia are present in the Tertiary basins in all three geographical provinces, viz. Sarawak, Sabah and Peninsular Malaysia (Fig. 1a). However, most of the coal resources are located in the states of Sabah and Sarawak, eastern Malaysia (Fig. 1a). The coals are thermal coal ranging from lignite to high-volatile bituminous B; nonetheless, coals with coking properties exist in the Bintulu, Silantek, Slimponpon and Maliau coalfields (Fig. 1a). The coal in eastern Malaysia currently is locally used, mainly for heating, by small industry for lime production. Several studies concerning sedimentology, geochemical and organic petrographic characteristics have been performed on Tertiary coals (Zulkifli et al., 2008; Sia and Abdullah, 2011, 2012; Alias et al., 2012; Mustapha and Abdullah, 2013). Coals have long been recognised as a source of gas, primarily methane and carbon dioxide, but its importance as a generator for oil is difficult to prove. However, coals are now known to be a significant potential source of liquid hydrocarbons in several basins in the word (Hendrix et al., 1995; Hunt, 1991; Murchison, 1987; Obaje and Hamza, 2000). Traditionally, coal petrographic studies mainly are used for determining coal quality, maceral compositions, paleodepositional environment, and coal rank (vitrinite-%Ro). Where coals are being assessed for their petroleum-generative potential, an organic petrology approach is most informative, whereby macerals are studied in relation to diagenetic and mineral matter and solid to soluble petroleum (bitumens, crude oils; Petersen, 1998). The recognition that coal is a contributor to oil accumulation has come from a range of geochemical techniques, which incorporate to coal petrography analysis such as Rock-Eval pyrolysis, solvent extract-gas chromatography-mass spectrometry (biomarkers), open system pyrolysis gas chromatography (Py-GC) (Wan Hasiah, 1999; Petersen et al., 2001; Farhaduzzaman et al., 2012; Alias et al., 2012) and hydrous pyrolysis (Taylor et al., 1998; Petersen, 2002; Walker and Mastalerz, 2004). In this study, we report the results of an investigation on Tertiary coals from two coalfields in eastern Malaysia (Fig. 1b), describing the organic petrography (maceral compositions), determining random vitrinite reflectance in oil (vitrinite-

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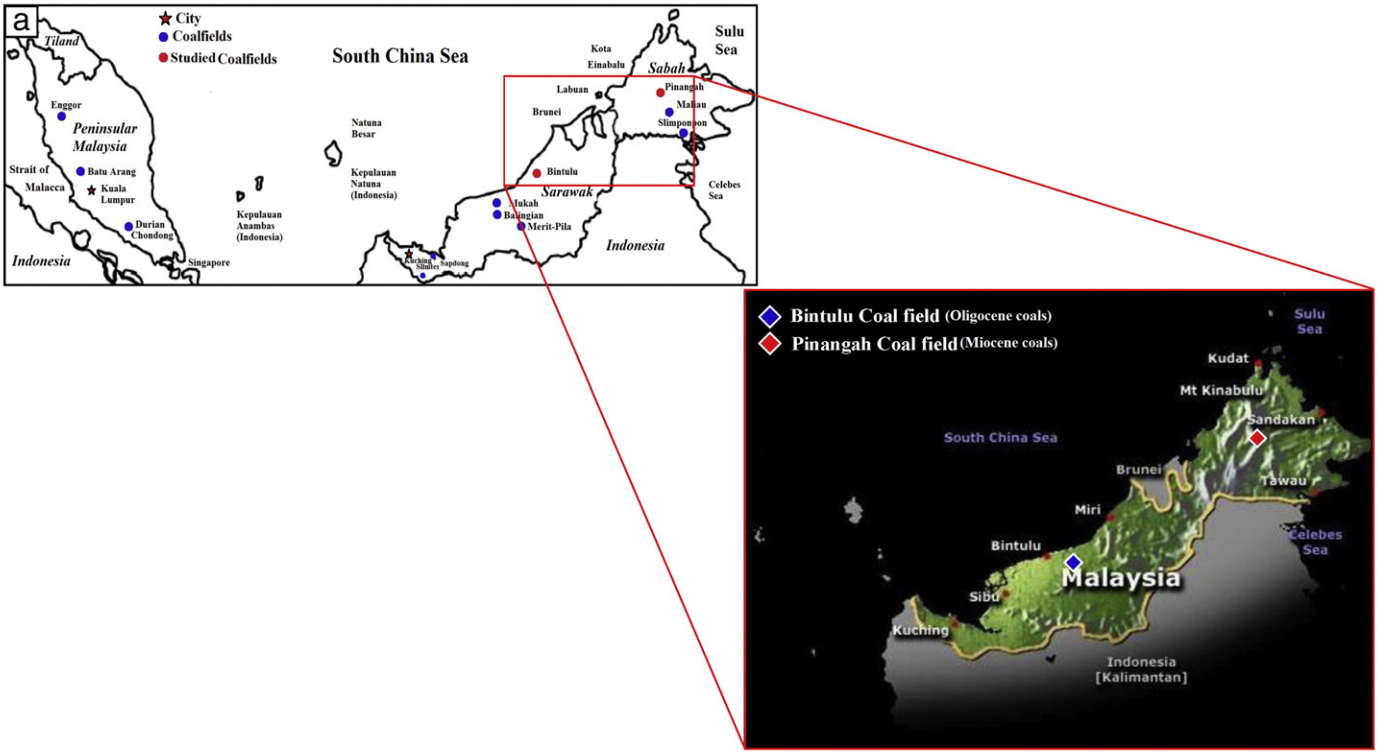


**Fig. 1.** (a) Location map showing the coal bearing Tertiary basins in Malaysia. (b) Location map showing coals examined in this study from eastern Malaysia, Pinangah and Bintulu coalfields.

%Ro; and coal rank), Rock-Eval pyrolysis properties ($T_{max}$, total organic carbon, and generated-hydrocarbons potential) and open system pyrolysis gas chromatography (Py-GC) (e.g. generated-hydrocarbons potential).

## 2. Geological setting

The Pinangah and Bintulu coalfields are located in the offshore area of eastern Malaysia (Fig. 1). The offshore area of eastern Malaysia currently is an active petroleum exploration area and thus an evaluation of hydrocarbon source rock perspective onshore can contribute to such an exploration activity. The Pinangah coalfield is underlain by the Tanjong Formation as was described by Collenette (1965) and consists of a sequence of mudstones, siltstones, limestones, conglomerates and coals (Fig. 2a). At least part of the Tanjong Formation was deposited in the shallow water, partly in brackish and estuarine environments, as shown by the presence of a carbonaceous material in the sandstone, fossil Textualaria, and the coal seams (Collenette, 1965). The depositional environment of the remainder of the formation in uncertain, but neritic conditions is assumed by previous workers. The Tanjong Formation is Early to Middle Miocene in the southern and eastern parts of Sabah (Clennell, 1992; Collenette, 1965; Leong, 1974). In contrast, the accumulation of the Bintulu coal took place in the Nyalau Formation during Oligocene–Early Miocene (Wolfenden, 1960). The Nyalau Formation is predominantly composed of sandstone–shale–mudstone and also contains coal seams (Fig. 2b), deposited in inter-distributor deltaic environments (Shushan, 2006). Coal seams are interbedded with sandstones and shale at many localities. These coals are believed to be inherited from terrestrial origin and deposited in a swamp environment under relatively oxic conditions (Wan Hasiah, 1999). The Nyalau Formation is believed to be the onshore analogue of the hydrocarbon-rich, offshore Balingian Province and is considered to contain important source and reservoir rocks for oil and gas (Du Bois, 1985).

## 3. Sampling and methodology

Twenty representative bulk coal samples were taken from coal faces at the Pinangah and Bintulu coalfields in eastern Malaysia (Fig. 1b). The organic petrographic and geochemical analytical methods including pyrolysis (SRA) and total organic carbon content (TOC) analysis proximate and open system pyrolysis gas chromatography (Py-GC) analyses, vitrinite reflectance measurements and macerals analysis, were performed at the organic geochemistry and petrology laboratories of the Department of Geology, University of Malaya.

All of the coal samples were screened by Source Rock Analyzer (SRA). The samples were crushed into fine powder (<150 μm) and analysed using (SRA-Weatherford)-TOC/TPH instrument (equivalent to Rock-Eval equipment). Parameters measured are TOC content and $S_1$, $S_2$, $S_3$ pyrolysis yields and temperature of maximum $S_2$ pyrolysis yield ($T_{max}$). Hydrogen (HI), oxygen (OI) and production (PI) indices were calculated (Table 1). Following pyrolysis, some samples with high HI values were selected for further geochemical analyses and microscopic examinations.

Part of the coal samples was ground to <150 μm and analysed on a Diamond Thermogravimetric–Differential Thermal Analyser (TG-DTA). Proximate analysis was carried out to determine moisture, ash, volatile matter and fixed carbon contents (Table 1) as followed by ASTM D388–12 (2012).

Open system pyrolysis gas chromatography (Py-GC) was also applied to provide compositional and structural characteristics of kerogen. An HP-Ultra1, 50 m × 32 mm i.d., dimethylpoly-siloxane-coated column (0.52 lm film thickness) was fitted into an Agilent GC chromatograph equipped with a pyrolysis unit and flame ionisation detector. Pyrolysis products were released over the range 300–600 °C (25 °C/min) and collected in a nitrogen-cooled trap. Identification of peaks based on reference chromatograms was done manually with Agilent ChemStation software. Organic petrographic examinations were performed on polished blocks to study macerals composition, thermal maturity and coal rank. The maceral analysis was performed on a Leica DM6000M